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ABSTRACT

This teacher's guide contains part two of the four-part first year Portland Project, a three-year secondary integrated science curriculum sequence. This part involves the student with unifying principles essential for deeper understanding of the concept of energy. Confidence in the atomic nature of matter is built by relating heat in terms of random molecular motion via the colorimetry experiment. The energy concept is then extended and generalized via various energy conversions, and finally, limitations and implications of energy conversion are explored, ending with a view of life as an organizer in nature, powered by energy, but always at the expense of influencing its environment. Notes to the teacher, examples of data, materials and equipment needed, and problem calculations are included. (SL)

the portland project

part two of an integrated science sequence

D. Wilson

HEAT, ENERGY, AND ORDER

YEAR ONE TEACHER GUIDE

TEACHER'S GUIDE

HEAT, ENERGY, AND ORDER

AN INTEGRATED SCIENCE SEQUENCE

1970 EDITION

DIRECTOR:
Dr. Karl Dittmer
Portland State University
Portland, Oregon

CO-DIRECTOR:
Dr. Michael Fiasca
Portland State University
Portland, Oregon

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HEAT, ENERGY, AND ORDER

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INTRODUCTION

In the previous part of this course you viewed the world in much the same way scientists do. The world is full of many fascinating phenomena and diverse things. Understanding comes from making careful observations, sometimes with special instruments that extend the senses, and from organizing all this information into a neat, comprehensible system for describing the observations. But there is yet a further step the scientist must make in his business of understanding nature. Besides great diversity in the world, there are also great underlying principles and ideas which are true for all things in many different situations. These are the concepts and laws of nature which make it possible for the scientist to see the relationship between all sorts of phenomena. They help him explain why things happen and to predict the results of yet untried experiments. In this part of the course you will be introduced to some important ideas of this sort.

Chapter I: HEAT

Calorie Chart	
Food	*Calories*
Beverages	
Buttermilk (8 Oz.)	*86*
Choc. Milk Shake	*495*
Milk (8 Oz.)	*165*
Skim Milk (8 Oz.)	*87*
Vegetables	
Cabbage, shredded (8 Oz.)	*25*
Carrots, 2	*50*
Potatoes	
fr. fried, 10 av.	*100*
hashed brown, (4 Oz.)	*150*

Hot fudge sundae? Apple pie a la mode? French fries? All these have plenty in common -- plenty of calories. But what is meant by a calorie? To a scientist it is a measure of heat. Is the calorie you are thinking about the same as everyone else's? You have used burners or heaters many times in your search for information about materials. How much heat were you using? Let's find out how to measure it.

A. TEMPERATURE, CALORIES, AND KEEPING TRACK OF THEM

A.1 - QUANTITY OF HEAT

If you had two beakers, one containing a lot of water and one containing very little water, and set under each of them a single alcohol burner, which do you expect would rise in temperature more quickly? If you wished to bring the two masses of water from room temperature to the boiling point in the same time you might be tempted to put more alcohol burners under the larger one. Whatever it is that the alcohol burner supplies to the water, apparently more of it is needed to raise the temperature of the larger amount of water.

Clearly there is another aspect to heating than temperature. Whatever is done to an object by a heater is done more by applying two heaters or by applying one heater for a longer period of time. We usually think of it this way: a quantity of heat is transferred to the object, and this causes the temperature of the object to rise. When more is transferred, the temperature in general rises higher. Cooling of our object is due to heat flowing out from it.

Does it take twice as much heat to raise the temperature of a certain amount of water by 2° C, as it does to raise it by 1° C? Does it matter whether the starting temperature is 20° C or 40° C? Does it take a different amount of heat to raise a gram of one substance 1° C than it does to raise a gram of another substance by 1° C? To answer these questions we must have a way to measure quantities of heat. It would also be very convenient to have a unit with which to state quantities of heat. This measuring unit is the calorie, which we will learn about in the next section.

Materials and Equipment

2 styrofoam tanks
2 electric immersion heaters
2 thermometers
stirrers (desirable)
Alternate possibility:
2 large (500 ml) styrofoam cups

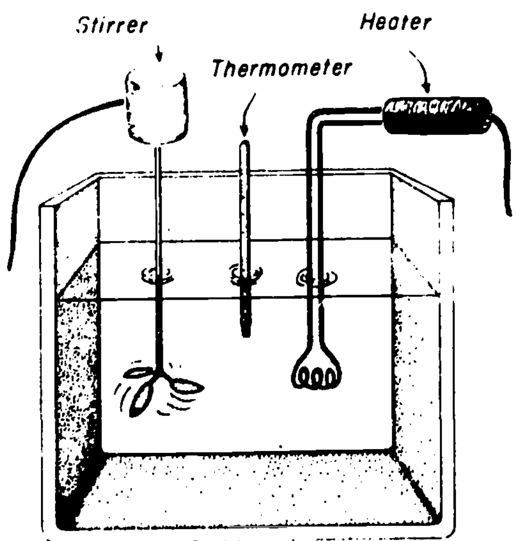


Figure A.1

Make sure the heaters are immersed to an equal depth. The thermometer should read to tenths of a degree. The subject of heat transfer will be taken up later. If the reason for using styrofoam tanks arises at this point, a preliminary discussion would be appropriate.

A.2 - Experiment: THE CALORIE

In this experiment we will heat different amounts of water in order to see whether there is some property of water which can be used to define a convenient unit for quantity of heat. (Water is a very convenient material to use for defining various units because it is so common and so important in many areas of science. For instance, the gram is defined as the mass of 1 cc of pure water.) The water will be contained in two styrofoam tanks, and for heaters we will use two electric immersion heaters of the type that are often used to warm water directly in a cup to make instant coffee. See Figure A.1.

First we must check to be sure that the two heaters deliver the same amount of heat in equal times. Place the same amount of water in each tank (2000 g) and check to be sure the temperature is the same in each. The stirrers should be turning throughout the experiment in order to keep the water mixed and free from "hotspots." Now turn on the heaters simultaneously. When the water in one of the tanks has risen by 10° C, turn both heaters off again. What is the temperature in the other tank? If the temperature in both tanks is the same it means that both heaters deliver the same quantity of heat in equal times. This is essential for the remainder of these experiments.

Large (500 ml) styrcfoam cups have been used successfully, adjusting water volume accordingly, always with the precaution to have the heaters immersed to an equal depth.

Now we will see what the effect will be of putting the same amount of heat into different amounts of water. One tank will be used to make sure we always are adding the same amount of heat. On each run refill it with 2000 g of water. The other tank will contain a different amount of water on each run. (From 1000 to 3000 g in 500 g steps is suggested.) Beginning each run with t e water in both tanks at a given temperature, and turning on the heaters long enough to produce a temperature rise of 10°C in the first tank, we will note the temperature rise in the second tank. The same amount of heat will go into the second tank on each run. Record the temperature change obtained on each run.

Sample results:

Mass (g)	*Temperature Change (°C)*	*Mass x Temperature Change (g x °C)*
3000	*6.7*	*2.00×10^4*
2500	*8.1*	*2.03×10^4*
2000	*10.1*	*2.02×10^4*
1500	*13.3*	*2.00×10^4*
1000	*19.8*	*1.98×10^4*

You might have expected to find that the water becomes hotter (rises in temperature more) when less of it is in the second tank. Is there a simple relationship involved? For instance, are the temperature change and the mass of the water inversely proportional? To check this, calculate the (mass of water) x (temperature change) for each run and list

The phrase "do not significantly change" means it is constant within experimental error. You might discuss and explain this idea. A graph of (m) (ΔT) vs. (m) would also help illustrate the relative importance of the experimental variations.

these with your data. If these values do not significantly change from one run to another it means mass and temperature change are inversely proportional. For example, if a mass of water rises in temperature by a certain amount, twice as much water would rise in temperature only by half the amount when supplied with the same amount of heat. If you did your measurements carefully you will have verified this fact.

Thus we have found a nice convenient property of water which can serve as a definition of a unit of quantity of heat. The name given to the unit is the calorie. A calorie is the heat required to raise 1 g of water 1 degree Celsius. The number of calories delivered (or removed) in any experiment is found by (temperature change in °C) x (mass of water in g). If water is not being used, the calories are given by finding the effect that same amount of heat would produce when added to water.

How many calories were added in each of the above runs? Can calories be added to substances other than water?

We have so far neglected to look into the matter of whether in the definition of the calorie it matters if the heat is added to the water at any particular starting temperature. To check this, two tanks, each containing 2000 g of water, can be heated. The first tank is refilled with cool water for each run, but the second is allowed to warm up from a different starting temperature each time. You should find that the (temperature change) x (mass) does not significantly depend on the water temperature.

This experiment might be fully or partly performed, or only the results given to the class, depending on time available.

Experimental data might be:

Range of Temperature (^oC)	*Temp. Change (^oC)*	*Mass x Temp. Change (g x ^oC)*
5-15	*10.2*	*2.04×10^4*
15-25	*10.2*	*2.04×10^4*
25-35	*10.1*	*2.02×10^4*
35-45	*9.9*	*1.98×10^4*

The downward drift in the last column may be due to heat loss. It is small, however--about 2%.

A.3. - Experiment: SPECIFIC HEAT

You probably aren't surprised at the idea that it takes a different amount of heat to raise the temperature of a mass of one substance than it takes to raise the temperature of another substance. For instance, have you ever heated up a heavy metal skillet or griddle on a stove? Although it may weigh as much as a large quantity of water the metal object gets very hot rather quickly compared to a pot of water. It apparently takes less than 1 calorie to raise the temperature of 1 gram of metal by 1°C.

The amount of heat required to raise the temperature of 1 g of a substance by 1°C is a quantity known as its <u>specific heat</u>. What is the specific heat of water? From our discussion just above you would expect that the specific heat of metal is less than that of water. In fact, most common materials have a smaller specific heat than water. Let us get a rough idea of the specific heat of some liquid other than water in the following experiment. The substance we will check is cooking oil.

Materials and Equipment

100 ml beakers
alcohol burners
cooking oil, more than one kind, if possible
thermometers

Be certain that students use 50 g of cooking oil rather than 50 ml of oil.

We might do this experiment with the styrofoam tanks and immersion heaters used in the last experiment, but not only would we hopelessly dirty the equipment but it would be very expensive to use enough cooking oil to make it practical. Instead we will use 100 ml beakers and an alcohol burner. As you may already realize, the alcohol burner does not give off heat very steadily, especially if there is a breeze in the room, but waiting 5 minutes after lighting it before beginning the experiment may help somewhat. Heat 50 g of water while stirring and note the time it takes for the temperature to rise from 30°C to 50°C. Do the same for 50 g of cooking oil using the same burner. Repeat for the water and for the cooking oil. Despite the variation in the results, due mostly to the unsteadiness of the heat output of the burner, you should be able to figure out a rough value for specific heat of the oil as follows: The amount of heat given to each sample is proportional to the time it is heated. For instance, if it takes one-third the time to heat the oil as it does to heat the water, then one-third as much heat is is given to the oil. Since one calorie is given to each g of water for each degree of temperature rise, one-third calorie would have been given to each g of oil for each degree. This would mean that the specific heat of the oil is 0.33. What do you actually find?

Approximately 0.5 is about right.

Specific heats can be determined not only for liquids but for solids and gases. Some values are given in the table. Note that the units are (cal/g)/°C. This means that the values indicate how much heat is required to heat a gram of material; for a gas this may be an extremely large volume of material.

Conceptually, (cal/g)/°C may be easier to understand, but when working problems the student may find cal/(g.°C) less confusing.

Typical values of specific heat (cal/(g.°C))

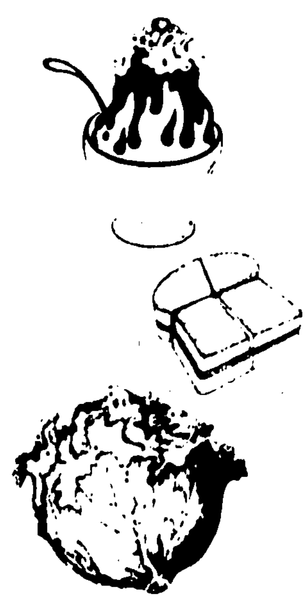
Aluminum	*0.21*
Lead	*0.03*
Iron	*0.11*
Hydrogen	*3.40*
Oxygen	*0.22*
Ice	*0.50*
Water (liquid)	*1.00*
Water (vapor)	*0.48*
Calcium chloride	*0.16*
Olive oil	*0.47*

B. - FOOD, CALORIES, AND GROWTH

B.1. - Experiment: CALORIES AND FOOD

Materials and Equipment:
(for 2 students)
- *beaker, 100 ml*
- *tripod*
- *wire gauze*
- *cork*
- *needle*
- *many nuts (of one kind)*
- *matches or a candle*
- *thermometer*
- *optional: tin can for calorimeters*
- *test tube*

You have learned that calories are a measure of heat, and generally we measure heat intensity in terms of temperature. Then we can say calories are the measure of the amount of heat you can get from that hot fudge sundae, from a hamburger, from an apple or a pickle. Just how much energy (measured as calories of



heat) is available from some common foods? We can find out using peanuts and filberts.

Using several successive pieces of nutmeat --peanuts, filberts, walnuts, etc.--try to find out how much heat is available from a given mass of nut. One way to start would be to stick a piece of nutmeat on a needle which in turn is embedded in a cork. Ignite the nutmeat, which should be in position under a small beaker (probably 100 ml) containing a measured amount of water. Measure the water temperature before and after burning the nut. If the nut stops burning, you may relight it once. If it goes out again, discard it and start over. Measure and record the available calories from three or four pieces of each kind.

Do your findings agree with those of your classmates? Did you get similar calorie counts each time? What factors are responsible for these inconsistent results? What might you do to increase the accuracy of your findings?

After devising an improved method or methods of measuring calories available from several samples of peanuts, walnuts, or whatever kind of nut you used, tabulate the data for the whole class. How many calories are available in 1.0 g of walnuts? In 1.0 g of peanuts?

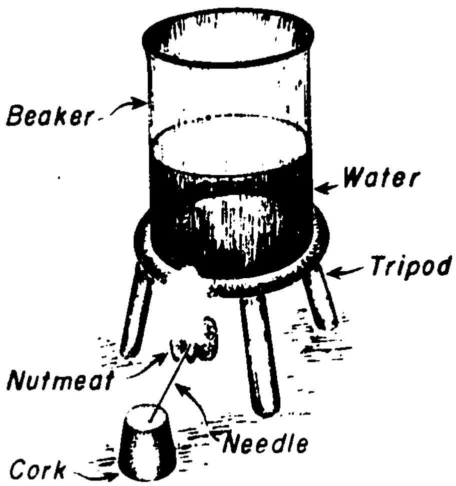


Figure B.1

Be sure the beaker contains enough water so that it will not boil away. Possible refinement:

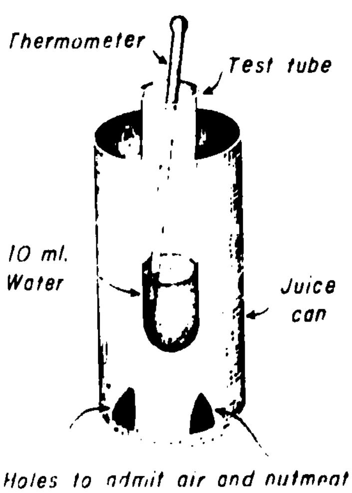


Figure B.2

While we have been talking about calories, we might also discuss the kilocalorie. You will recall that the prefix "kilo-" in the metric system means "multiply by 1,000." Therefore, a kilocalorie equals 1,000 (10^3) calories. The nutritional calorie is the equivalent of a kilocalorie; therefore, a diet drink labeled 3 calories per can actually has 3,000 calories or 3×10^3 calories food value. From your data, how many kilocalories are there in 1.0 g of peanuts?

Because there is insufficient control over experimental conditions, they can be expected to vary considerably.

Any kind of edible nut will do.

Calories available in some common nuts:

Nut type	*cal/g*
almond	*6000*
brazil	*6460*
cashew	*5860*
filbert	*6460*
macadamia	*7260*
walnut, English	*6125*

Do both kinds of nuts provide equal amounts of heat? Where was the heat before you burned the nut? Would other foods also serve as a potential source of heat? What do you mean by "food"?

No, both do not provide equal heat. Before burning, the heat was stored in the molecular structure of the nut.

Food is digestible stored chemical energy. In this sense all foods are a potential source of heat. Later on it will be pointed out that cellular respiration is 40-50% efficient whereas efficiency of the whole organism is about 25%.

Note that "burning" food inside of you is similar to burning the peanut in that both are combustion or oxidation processes. (In burning, the nut combines with oxygen.) In some instances, however, "burning" (oxidation) may be a very slow process and not accompanied by a measurable amount of heat.

HDL's 10, 11, and 14 go with this section.

Do you use all your available heat efficiently or is some of it wasted? Does it all go to keeping you warm? Can you think of some examples? What if you take in more than your body needs?

Examples of waste: heat losses

Excess food is stored in high-energy fats.

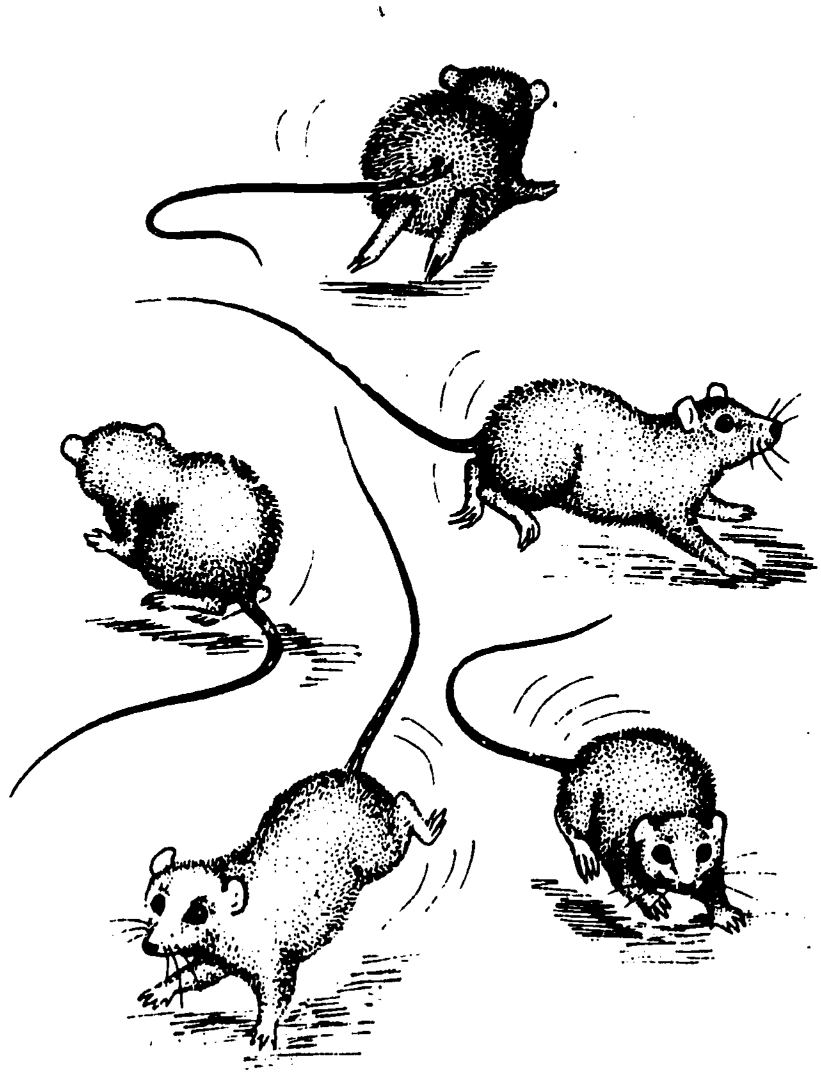
A mouse colony must be started after Christmas. Order mice that are genetically pure for one trait, e.g. color or ear size, and be prepared with cages. Experience shows 4 pr. mice + 4 months ⟶ 80 mice requiring at least 12 cages and $25 for food and cedar chips.

If you want useful data, the kids will need lots of guidance. The following sections rely on Mouse Data:

<u>Heat, Energy, and Order</u>
I.B.2 Food and Growth
III.D.4 First look at the Mouse Data

<u>Mice and Men</u>
I F. Maturation
II A. Mouse Genetics
E.1 Gene frequencies in the Mouse Population
IV A., A.1 Mouse Colony as a Population
A.2 Biomass of the Mouse Colony

The mice will eat, grow, mate, and reproduce with great success. A huge amount of data is there. The problem: organizing and gathering the information.



B.2. - FOOD AND GROWTH - LOOKING AT THE MOUSE COLONY

What happens to those calories from the food? Where and how do organisms utilize this energy?

We will pursue some aspects of this problem through the mice which are available. You will not get complete answers to the questions asked and others may come up as you try to find out about the energy used by mice. Keeping a more detailed record of what is going on in the colony over a period of time will help answer questions such as how much food does a mouse need, how many calories does this represent, do males or females need more food.

As you gather data, plan to graph the results for your F_1 mice (the first-generation offspring) and the colony in order to answer at least the following questions:

1. How much food and water does an adult mouse use in a day?

2. How much food and water does a growing mouse use in a day?

3. Does a mouse gain as much weight in grams as the difference between input (food and water) and output (feces and urine)?

Now the real amassing of mouse data begins. This is an ongoing activity which should be given some regularly scheduled time. (E.g. 10-15 minutes Mon., Wed., Fri. or 10-15 minutes Mon., Thurs.)

Usually students do this sort of thing at the beginning of the period without being told.

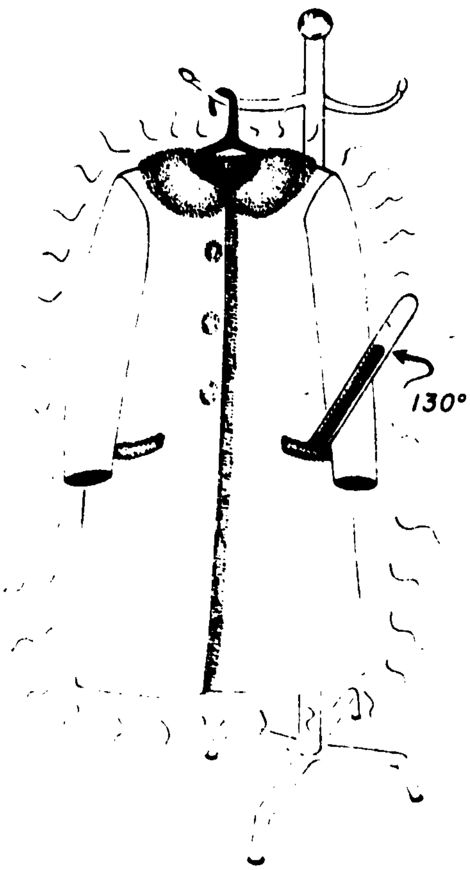
Students will need more time on a few days spaced out through Book II. Which day is not critical, but try for two or three full periods for the mouse work. This time is for measuring non-routine items such as feces and urine production, the relationship of food and water, products in vs. products out, and Δ M.

1. From class data.

2. From student data

3. No

4. The colony mass and colony intake of food should go along together--both geometric.



Materials and Equipment
(per team)
[illegible] large beakers or bowls
[illegible] or more thermometers
Ice--plenty of it
Stirring rod or stick

4. Is there a pattern in the relationship between food-water, feces-urine and growth in mass of the colony as a whole?

You are encouraged to try to answer other questions. Your teacher will help you learn how to use the available data or determine what other information you will need to gather.

It will take many weeks of observation to gather enough information to answer these questions.

C. - HEAT TRANSFER

Why do you wear a warm coat in the winter? In fact what do you mean by a "warm coat"? Is it really warm, i.e., does it have a high temperature? Or is it simply preventing the heat that you generate by burning food from escaping from you? In this section we will look at some of the aspects of moving heat from one object to another or from one place to another.

C.1. - Experiment: HEAT LOSS BY CONDUCTION

Into four large beakers or bowls put enough water to cover your hand. With a thermometer in each, add ice to bring the water to 10°C. When the water has reached 10°C, remove the ice. Put your hand into the first bowl, holding it still for 5 minutes while your partner reads and records the temperature of the water at the end of each minute. The water in the beaker should be stirred gently with a rod during the entire period. At the end of the 5-minute period immediately plunge the same chilled hand into the second bowl of 10°C water and repeat the process for another 5 minutes. Have your warm-handed partner record the temperature readings. Now put your other, unchilled hand into the third bowl (also at 10°C), but as you hold it in the water move your fingers vigorously for the 5-minute period. Temperature in the fourth bowl should also be recorded for 5 minutes without holding your hand in the water? Why? With the accumulated data make a graph. Explain why the lines are not all the same. How could you calculate the number of calories put into each bowl?

The fourth bowl is a control.

The four lines vary because of variation in conditions.

Comparisons can be made on basis of hand size, male or female, better than an explanation of factors such as evaporation, friction from agitation.

To calculate calories/bowl, measure volume of the water and multiply by heat change.

When two objects are in direct contact they exchange heat by a process called <u>conduction</u>. The amount of heat transferred is greater if the difference in temperature is greater. Does this help you understand that the shipwreck victim tossed into a very cold ocean soon dies because his body does not contain enough energy to heat the whole ocean, and he cannot burn food fast enough to make up for his heat loss?

Materials and Equipment
(per team)
hot water
thermometer
plastic bag--1 gal. food storage type
ringstands (2)
clamps (2)

From an open pan of water heat is transferred to the surroundings.

Heat from lakes and other bodies of water is lost to surroundings; such loss helps moderate the climate.

The lake with the larger surface would be a more efficient transmitter of heat.

HDL 15 goes with this section.

Temperatures should be read only to the nearest 0.5 degree.

Experimental data:
Temperature Change
from round shaped bag:
8°C in 15 min.
10°C in 20 min.
from cigar shaped bag:
16°C in 15 min.
19°C in 20 min.

Alternatively, you might compare heat loss from water in a 100 ml (stoppered) flask with heat loss from a large test tube or graduated cylinder.

If the bag were laid on a counter top, heat loss relative to position in air would depend on the thermal conductivity of the counter material.

C.2. - Experiment: HEAT LOSS AND SURFACE AREA

If you set a pan of hot water on the kitchen counter or the demonstration table, what happens to the heat? In some regions there are many lakes, large and small. The summer sun may warm them for several months. What happens to the heat held in such bodies of water as fall and winter come? Would two lakes of equal volume lose heat at the same rate if one were small and deep while the other was broad and flat?

Would a round balloon containing hot water (or a hot gas) lose heat as rapidly as a long, thin balloon containing the same volume of hot water? You can test this using watertight plastic bags. Into a plastic bag pour 400 ml of hot water (between 60° - 70° C). Insert a thermometer and suspend from a support stand or hold the bag quietly while your partner records the temperature readings at regular intervals for 15 minutes. Empty the water from the bag and repeat the process. This time, however, suspend the bag between two supports or hold it in such a way that the water is spread out over a much larger area of the bag. Be sure that the thermometer bulb is immersed. Would you get the same results by laying the bag of water on the counter top? Does this experiment tell you something about relative heat loss from a garter snake and a grass frog each weighing about 50 grams? When you climb into a cold bed, what is the most comfortable position to assume?

The snake should lose more heat than the frog because of difference in surface area: volume ratio. For excellent disquisition see PSSC, Chap. 4, sec. 5.

This may be a suitable time to investigate differences in surface area: volume ratio as noted in different climates. This would include comparing sizes of ears, paws, tails, etc.

C.3. - Experiment: HEAT TRANSFER

Heat can be transferred between one body and another even when there is no contact between them. It is not even necessary that there be air in the intervening space. For instance we are warmed in the sunlight although there is 93 million miles of practically empty space between us and the sun. This is called transfer of heat by radiation or simply radiant transfer.

Materials and Equipment

- *100, 150 or 200 watt light bulb, socket*
- *3 flasks of same size, fitted with one-hole rubber stoppers and thermometers*
- *aluminum foil to cover one flask*
- *source of soot for 3rd flask or flat black paint*

Place a bulb 100 watt or bigger in a socket on a table. At equal distances from it place several identical flasks, air-filled, stoppered, and with a thermometer in each. One flask is covered with aluminum foil, one has a black surface, and one is left uncovered. Take initial temperature readings in each. Turn on the bulb and take temperature readings at 1 minute intervals. If 1 minute intervals are not satisfactory, change to a different

About 19 cm from a 150 or 200 W bulb to each flask works well time interval. After 10 to 15 minutes of heating, turn off the light bulb and continue to record data for about 10 minutes. Then plot a temperature vs. time curve for all three flasks on one graph. What curves are you plotting? Which surface absorbs the most heat? Which the least? Why do you think this is so? Why do the curves reach a plateau? Suppose the bulb had a higher heat output. How would this have affected the curves? Was the best heat absorber the best radiator of heat? How do you know the bulb radiates equally in all directions? How could you find out?

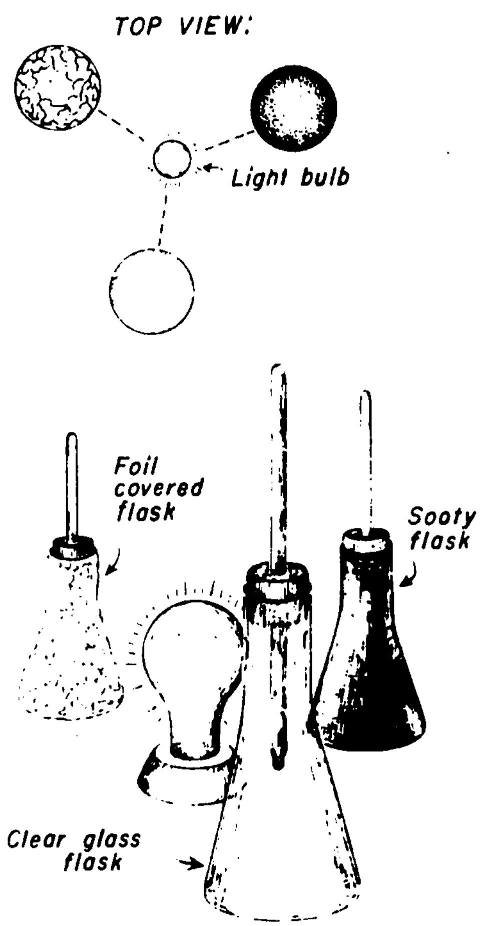


Figure C.1
Apparatus for Radiation Absorption Experiment

After the heat source is turned off, the student will be plotting cooling curves. One would expect the black surface to absorb the most heat; the aluminum foil-covered surface, the least.

The student can experiment with many other surfaces besides those indicated in the text. More than three at a time can be used.

Plateaus in curves represent equilibrium between absorption and loss.
In the case of the bulb with a higher heat output, the curves would probably have a steeper slope but a higher plateau. If the best absorber were not also a fine radiator, this absorber might take up all the energy around.

Could reflection off the aluminum foil-covered flask hit the others and add to their radiation? This could be avoided by erecting a cardboard divider.

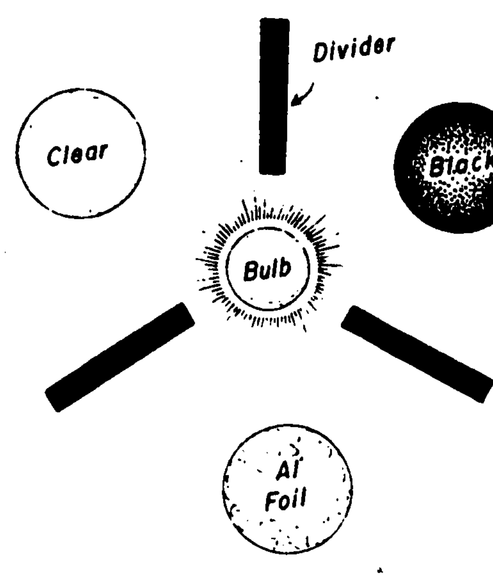
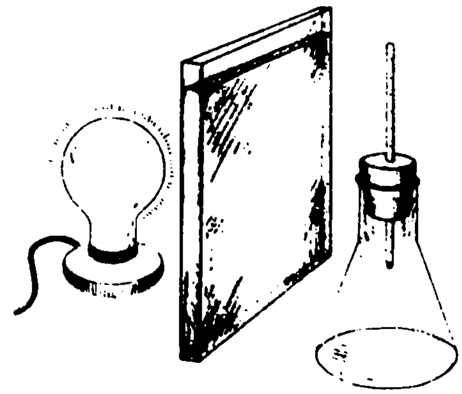


Figure C.1.a

To show that it is not simply transmitted visible light being converted to heat that is involved, the teacher might try an experiment with an improvised infra-red filter. The filter can be constructed of 2 sheets of plate glass, separated at the edges by modeling clay and filled with water. About ¼" of water thickness may be enough.



The transmitted visible light is relatively unchanged, as can be checked with a light meter, but the heat transfer of the radiation is much reduced.

D. - HEAT LOSSES AND HEAT GAINS

We have seen that when a substance gains heat, all other things remaining the same, it will rise in temperature. If it loses heat it will decrease in temperature. Thus when two bodies having different temperatures are in contact one will cool off while the other will warm up. Is there some way of predicting what the final temperature will be?

"other things remaining the same," i.e., assuming the volume, chemical state, etc. are unchanged. Later, the possibility of gas expansion, etc. will be considered.

D.1. - Experiment: COOLING AND WARMING IN A MIXTURE

Let us observe what happens when materials at different temperatures are brought together. For convenience and because we are familiar with its properties let us use two volumes of water. We can make excellent contact between them by simply pouring them into a single container. In order to get reasonable accuracy we will use a container which will not permit much transfer of heat to the room. This is a covered cup made of styrofoam, the same material that you used in the immersion heater experiment. A further improvement can be made by setting the cup in a beaker, so as to minimize movement of air at the surface of the styrofoam.

Materials and Equipment:
- *styrofoam cups, each with a lid cut from base of another cup*
- *beakers*
- *thermometers*
- *warm, cold, and hot water*

This is the simplest sort of experiment of the type called "calorimetry." The cup is a "calorimeter."

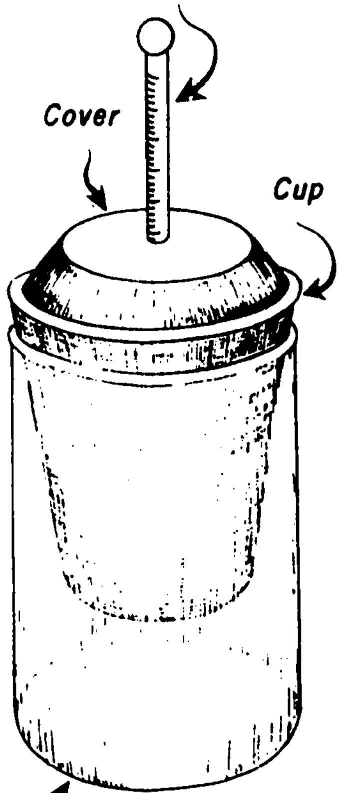


Figure D.1

The air would carry heat. This is often called heat transfer by convection. The word convection has not been introduced, however, in order to keep the vocabulary to a minimum. Moreover, it is not an essential idea, as it is simply a combination effect involving conduction and mass transfer.

Multiply the mass of the cool water by its temperature change. Similarly for the hot water. The results should be equal.

E_h *(calories) = mass x temp. change*

or temp. change = $\frac{m}{E_h}$

where E_h *= Heat Energy*

Into the cup pour 75 cm^3 (very close to 75 g) of cool tap water. Carefully note its temperature. Then add to it approximately 75 cm^3 of water at the boiling point. Cover the cup quickly and note the temperature of the mixture after it has settled down to a steady value. (The amount of hot water added is about 75 g, but it can be checked accurately by weighing the cup and contents before and after it is added.)

How much heat was gained by the cool water? How much heat was lost by the hot water? What do you conclude? You may wish to repeat this experiment using unequal volumes of water. Is there some general principle that this experiment seems to lend support to, that would enable you to predict the final water temperature before you actually measure it?

If the cool tap water was 20^oC:

calories gained by cool water = (mass of cool water)(Δt)

calories lost by hot water = (mass of hot water)(Δt)

Since: calories gained = the calories lost,
$(mass_1)(\Delta t_1) = (mass_2)(\Delta t_2)$

If the initial temperature of the cool water was 20^oC and the initial temperature of the hot water was 100^oC, it is possible to determine the final temperature as follows:

Let X = final temp.
$(75)(X-20) = (75)(100-X)$
$X = 60^oC$

See HDL's 14 and 15.

D.2. - THE CONSERVATION OF HEAT

Many experiments of the type you have just performed have led to a generalization about heat which says that when heat flows from substance to substance it neither increases nor decreases in the process. Its total stays the same. Heat is said to be "conserved." For these experiments, often called calorimetry experiments, this idea of heat conservation apparently holds true, even for solids and gases. In fact, calorimetry is an important method for measuring such properties as specific heat.

It is important to note, however, that calorimetry experiments are rather special kinds of experiments. They constitute a relatively simple, though important, type of measurement in which the main idea is to bring substances of differing temperature into contact. No forces are applied to the materials. Lots of jiggling and moving of the material is not permitted. For more complicated kinds of experiments, the idea of heat conservation will have to be extended as you will see. But we have made a very good start.

The allusions here are to external work (mechanical energy) and friction. Chemical changes would also cause problems.

D.3. - WHAT IS HEAT? WHAT ISN'T IT?

You may have already formed an idea about heat which was believed by scientists for many years. Heat seems to be like an indestructible fluid which can flow in and out of a body and make it seem hotter and colder. It is neither created nor destroyed. For calorimetry experiments this is in fact a perfectly good way to view heat. However, there are some cases where this is not a good way to look at heat. Did you ever get a "hot seat" by sliding down a banister? In such a case we say heat is produced by "friction"; it turns out it can actually be generated in unending quantities this way.

The caloric theory, abandoned in the 1st part of the 19th Century.

WARNING! You will need sea urchin eggs for the experiment: FERTILIZATION in the first chapter of MICE AND MEN.

Exercises for Home, Desk, and Lab (HDL)

(1) A thousand grams of water are heated with an immersion heater. The temperature of the water rises from 10° C to 25° C. How many calories have gone into the water?

(1) 15,000 calories
$(1000g \times 15^{\circ} \times 1\ cal/g^{\circ}C)$

(2) A certain heater coil is known to supply 1000 cal/min. If this coil is placed in 500 g of water in an insulated container, (a) how many calories will the coil supply in 2 minutes, and (b) what will be the temperature rise in 2 minutes?

(2) (a) $1000\ cal/min \times 2\ min = 2000\ cal$

(b) $$\frac{2000\ cal}{(500g)(1\ cal/g^{\circ}C)} = 4^{\circ}C$$

(3) In the experiment described in part A.2., what would have been the temperature rise if 4000 g of water had been heated in the second tank while 2000 g of water in the first tank were heated 10° C?

(3) $2000g \times 10^{\circ}C \times 1\ cal/g^{\circ}C = 20{,}000cal\ (2 \times 10^{4}cal)$

$$\frac{2 \times 10^{4}\ cal}{(4 \times 10^{3}\ g)(1\ cal/g^{\circ}C)} = 5^{\circ}C$$

(4) How many calories are needed to heat 1 g of water from its freezing point to its boiling point?

(4) 100 calories

(5) Find the heat output of your home or apartment furnace or heater.

(6) Determine some of the various ways in which heat used in your community is measured.

(6) Some ways include calories, kilocalories, BTU (British thermal units), BTU/hr.

(7) (a) How many calories would be required to raise the temperature of an iron frying pan from room temperature to 250° C? Assume room temperature to be 20° C and the frying pan to weigh 3000g.

(b) How much water can be raised from room temperature to the boiling point with this heat input?

(8) (a) If the frying pan in problem (7) were filled with 500 g of olive oil how much heat would be required to raise the temperature of the oil from 20° C to 250° C?

(b) How much heat would be required to raise the temperature of the pan and oil, combined, from 20° C to 250° C?

(9) Does heat differ from temperature or are the two the same? When you measure the temperature of ice water or when you take your temperature are you actually measuring heat?

If you had a bathtub full of boiling water and took one cupful of water from it, would the water in the tub and the water in the cup have the same temperature? Would they contain equal quantities of heat? Which would take more ice cubes to bring it to 45° C?

For questions (7) and (8) the teacher will have to supply specific heat values for iron and olive oil.

(7) (a) $E_h = (3.000 \times 10^3 g)(250^oC) \underset{\text{specific heat}}{(.11 cal/(g^oC))}$

$E_h = 7.6 \times 10^4$ cal

(b) $\frac{7.6 \times 10^4 \text{ cal}}{(80^o)(1 cal/g^oC)} = 9.5 \times 10^2 g. \ H_2O$

where E_h = heat energy

(8)

(a) $E_h = (500g)(230^oC)\underset{\text{specific heat}}{(0.47 cal/(g^oC))}$

$E_h = 5.4 \times 10^4$ calories

(b) $7.6 \times 10^4 cal + 5.4 \times 10^4 cal = 1.3 \times 10^5$ cal

(9) Heat and temperature are not the same. Temperature is a measure of random molecular motion designated in degrees. Heat is a form of energy. Only under certain conditions is the amount of heat absorbed proportional to the change in temperature.

Taking one's temperature does not measure heat.

A bathtub full of water and a cup of water would have the same temperature but would not contain equal heat.

(10) Problem of eliminating the water, which makes up much of the material, before measuring the caloric content.

(11) Low: lettuce, tomatoes, celery, cucumbers, etc.
High: ice cream, butter, raisins, chocolate

(12) Temperature does not change as rapidly when heating first begins and in the range of 80°C-100°C. This is probably due to energy exchanges between the source and the beaker and/or the atmosphere.

(13) Yes. The student may suggest one of several methods. One method suggested is to exhale a measured volume of breath into a predetermined mass of water. Calculate the energy input from the ΔT of the water times the mass of water. This will give a close approximation of the heat loss.

(14) (a) $\frac{10 \times 25}{.3} =$
833 cal/g
8×10^2 cal/g
or 8×10^{-1}kcal/g

(b) $\frac{8 \times 4}{.7} =$
45.7 cal/g
5×10^1 cal/g
5×10^{-2}kcal/g

Both (a) and (b) are rounded off because there is just one significant figure.

(15) Buy a big block. Reduced surface area results in lower heat loss to surroundings, and therefore less loss due to melting.

(10) What problems would arise if you attempted to measure the kilocalories in milk? Cheese? Tomatoes?

(11) What are some low-energy foods? Some high-energy foods?

(12) Imagine you plotted a graph of temperature against time for water being heated from 0°C to 100°C. Would you predict that it takes less time to raise by 5°C the temperature of water at 90°C or water at room temperature?

(13) Could you measure heat loss from your exhaled breath? How?

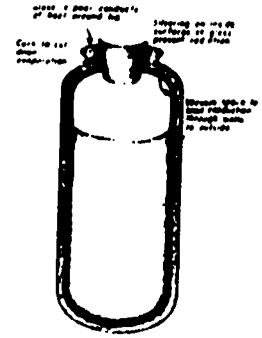
(14) (a) If burning a 0.3 g piece of peanut raises the temperature of 10 ml of water 25°C, how many calories/g are available in the nut?

(b) If burning a 0.7 g cube of dehydrated cheese raises 4 ml. of H_2O 8°C in temperature, how many calories are available per gram of cheese?

(15) You are shopping for a big party to be held 8 hours from now. The ice which you buy will be carried around in the trunk of your car, then stored on the patio until party time. Which should you buy--a large block of ice to be

chipped up later, or an equal weight of ice cubes? Why?

(16) Find out how a vacuum flask ("Thermos" bottle) is constructed and explain why it keeps heat in (or out).



(17) (a) If 300 ml of 70° C water is mixed with 700 ml of 100° C water, what will be the temperature of the final mass?

(b) If 100 ml of 25° C water is mixed with 400 ml of water at 45° C, the final temperature of the total will be ______?

(c) What will be the final temperature if 125 ml of milk at 18° C is mixed with 250 ml of milk at 72° C?

(18) A bathtub contains 1.0×10^5 g of water at 25° C. How much water at 60° C must be added to provide a hot bath at 40° C?

(19) (a) In each of 2 beakers there is 100 ml of liquid at 20° C. To each you add 100 ml of 90° C water. The temperature in beaker X soon reaches 55° C. The temperature in beaker Y soon reaches 75° C. How would you explain this?

(17) (a)
Heat lost by Hot Water = Heat Gained by Cold Water

Heat Lost by Hot Water =
Sp. Heat Grams ΔT
(1 cal/g°C) (700g)(100°C -Final Temp)
Heat Gained by Cold Water =
(1 cal/g°C) (300g)(Final Temp - 70°C)

(1cal/g°C)(700g)(100°C - Final Temp) = 1 cal/g°C)(300g)(Final Temp) - 21000

91,000 = (1000)(Final Temp)
91 = Final Temp

(b)
(100)(X-25) = (400)(45-X)
X = 41°C

(c)
(125)(X-18) = (250)(72-X)
X = 54 assuming SpH Milk = 1 cal/g°C

(18) To raise the temperature of 1.0×10^5 g of water 15°C requires $15 \times 1.0 \times 10^5$ cal/g or 1.5×10^6 calories. This heat must come from the 60° water, which will be cooled to 40° C. Needed mass =

$$\frac{1.5 \times 10^6 \text{ cal}}{20^\circ \times 1 \text{ cal/g/}^\circ \text{C}} =$$

7.5×10^4 grams

(19)
(a) Not all substances can take up equal amounts of heat; that is, different substances have different specific heats.

(b) 0.03 cal must leave each gram of mercury at room temperature for each ^{o}C change in temperature.

(b) It takes less ice cubes to chill 1000 g of mercury from 50° C to 20° C than it does to chill 1000 g of water through the same temperature range. Can you explain this?

(20) Prepare three drinking glasses in the following manner:

A - no treatment

B - wrap in newspaper

C - wrap in crumpled newspaper and set in larger glass or mug

Into each pour 100 ml of hot water. Measure the temperature of each at regular intervals for 20 minutes, then plot the cooling curves. Is 20 minutes sufficient for tracing the change?

(a) What does this teach you about insulation in homes?

(b) Why are wool blankets effective as bedding?

(c) Why can birds perch outdoors at 0°C without freezing to death?

(d) Are feathers or fur better insulation?

(e) Would lids on the glasses make any difference?

(f) Could this experiment have started

with ice-cold water?

Repeat experiment with a thermos bottle.

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
Chap. II Temperature and Chaos							
A. Atoms and Molecules							1
A.1 Models							
A.2 Atoms							
A.3 Molecules				CHEM Study film "Molecular Motion"			
B. Atoms and molecules in motion	4 Days						
B.1 Brownian motion			B.2 The Brownian motion of smoke particles				
B.3 Relevance of Brownian motion to temperature							2,3,4
C. Some familiar phenomena and their explanation							
C.1 Heat conduction							

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
			C.2 Diffusion				
C.3 Evaporation							5

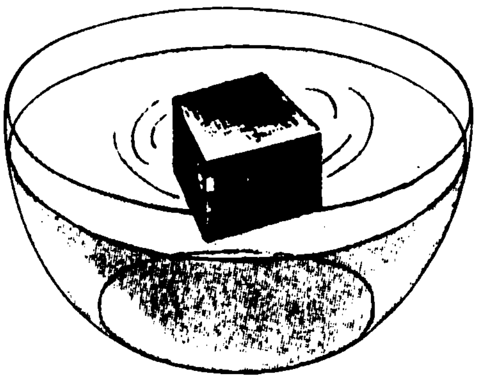
Chapter II: TEMPERATURE AND CHAOS

Heating an object can cause its temperature to rise. Just what do we mean by rising temperature? So far we have meant only that a thermometer has indicated a higher value. Does it have any deeper meaning than that? Does it have a meaning that can explain other observations about heat, such as conduction? In this chapter we shall look into some of these questions.

A. ATOMS AND MOLECULES

A.1. - MODELS

In science it is not enough to simply describe what we see or measure and then to classify what we observe. We are basically interested in the "why" and the "how" of our observations. To do this we often imagine the hidden structure of the objects in which we are interested and then note whether our observations are in logical accord with this imagined structure, which we call a "model." A model must provide an explanation for all of our observations and yet not be in contradiction to any of them. Insofar as the observations are consistent with our supposed structure, we can say that the model describes reality.



Sodium has a violent chemical reaction with water.

A simple example may help illustrate this idea. Suppose we have a metallic block and we notice that it floats in water. Why does it float? One possibility is that it is made of a very light metal. We go to the Handbook of Physics and Chemistry and discover that there is no metal which would be light enough to float on water and yet not be destroyed by the water. We then propose that the cube is hollow; this is a tentative "model." It explains at least one characteristic of the block, viz., its ability to float. However, when we tap the cube with our finger it doesn't sound hollow. The model doesn't pass our test and has to be revised. Perhaps it is simply a wooden block painted with metallic paint. This model might fail on the basis of any of several tests, such as whether it is in accord with the measured conductivity of the block. As we do more and more tests on the block the possibility that the model might fail one of them is always there. (Can you think of some additional tests?) However, if the model we decide upon continues to pass all of the tests, we can feel more and more

X ray pictures, ability to attract a magnet, specific heat, hardness, etc.

assured that it is a "true" description of the block. We should realize, of course, that we might settle on a model that is presently in accord with all our tests but is later shown to be false--for instance, when we get around to cutting apart the block. However as far as our experiments go, if the model continues to pass muster, we can regard it as a true description of reality.

A.2. - ATOMS

Many of the phenomena that occur in nature can be explained by supposing that all matter is made up of very tiny bits of matter known as atoms. This idea, known as the atomic hypothesis, has been found to be an excellent model for all matter. It explains many observations made in many fields of science over many years, including those you have made in your study of heat. Insofar as the discoveries of science go, it continues to the present day to be an excellent description of matter; it accords with reality.

What are atoms made of? Do they move? How fast? How are they related to heat? Some of these questions will be answered as we proceed in our study of science. To begin with, however, we ought to have an appreciation for the size of atoms. Every bit of matter which you handle in everyday life contains an enormous number of atoms. Some idea of how many atoms fit into a small space can be given by the following example: Suppose you could somehow mark all of the atoms in a glass of water. Suppose also, you were able to stir the contents of the glass into the sea so that it mixed thoroughly with all the water of the oceans of the world. If you then took a glass of water out of the ocean it would still contain about 300 of your original atoms.

A.2.a. - THE NATURE OF ATOMS

Such fantastically small objects cannot be seen, even with the best microscopes. Yet physicists and chemists know an enormous amount about them. They know that the outer parts of atoms are made up of bits of matter called electrons, the motion of which constitutes an "electrical current" in wires. The even smaller particle at the very center of an atom contains most of its mass; this region is called the nucleus of the atom. In the last 50 years or so a great deal has come to be known about the nucleus. Surprisingly it has been found to contain yet tinier bits of matter known as nucleons. How can scientists find out all these things about objects which are too small to be seen? The answer is, of course, by the use of models and the testing of these models by experimentation. We shall see examples of this procedure as we continue our study.

A.3. - MOLECULES

Atoms are assembled in various ways to form all the substances we deal with in every-day life: wood and wire, pencils and chewing gum, air and water, and living things--including ourselves. In most cases atoms are assembled in special combinations which constitute the smallest piece of matter which can be identified as a particular material, i.e., a molecule of that material. For instance, the special combination of two atoms of the gas hydrogen with one atom of the gas oxygen constitutes the smallest piece of matter which can be properly called "water." The combining of atoms in this way is known as a chemical combination. Thus a molecule of water can be said to arise from a chemical combination of hydrogen and oxygen.

The CHEM study film "Molecular Motion" may well be used here.

B. - ATOMS AND MOLECULES IN MOTION

B.1. - BROWNIAN MOTION

If you look through a low-power microscope at some tobacco smoke particles suspended in air, you will see that the particles have a random, jerky motion. This effect is called Brownian motion in honor of Robert Brown, who in 1827 discovered a similar motion in pollen grains suspended in water. A French physicist, Jean Perrin, later provided a qualitative explanation. He said that the random motion was due to the liquid (or gas) molecules striking the small suspended particles unevenly. In 1905 Albert Einstein published a complete mathematical treatment of Brownian motion. But before we say more, let s take time out to see for ourselves.

In order to contain the smoke, you will need a chamber which can be placed on a microscope stage. Such a chamber is listed in scientific supply catalogues under the designation "Brownian Motion." An improvisation, however, will do. Try to eliminate convection currents in order not to obscure the random erratic motion of the smoke particles.

B.2.a -Alternate Experiment: THE BROWNIAN MOTION OF LEAD CARBONATE CRYSTALS

B.2. - Demonstration: THE BROWNIAN MOTION OF SMOKE PARTICLES

Smoke particles are so small that it is difficult or impossible to see what they look like with an ordinary microscope set-up. We may, however, see smoke particles by shining a strong light on them in such a way that only the light which scatters from the smoke enters our microscope. A 40-to 60-power microscope works well. Using this technique, smoke particles will appear as tiny stars against a dark background. Notice that the smaller particles exhibit more Brownian motion than the larger ones.

The effects you have just seen are due to the fact that air is composed of separate molecules. A smoke particle is so small that it can be knocked around by the even smaller, faster air molecules which are striking it randomly on all sides. We cannot see the air molecules, but we can infer their existence from the zig-zag motion which they impart to the smoke particles. A detailed treatment of our observation would relate the size of the air molecules and the size of the smoke particles to the amount of Brownian motion we observe. If the air molecules were larger, objects like BB's would exhibit Brownian motion, whereas if the air molecules were smaller, we would not see Brownian motion at all.

If a few drops of lead acetate solution are placed in a dilute sodium carbonate solution, minute lead carbonate crystals precipitate out. If a drop containing $PbCO_3$ crystals is placed on a microscope slide which is lighted from the side and viewed under low power, one may see Brownian motion in a liquid. These tiny particles are flat and catch the light as they show rotational Brownian movement.

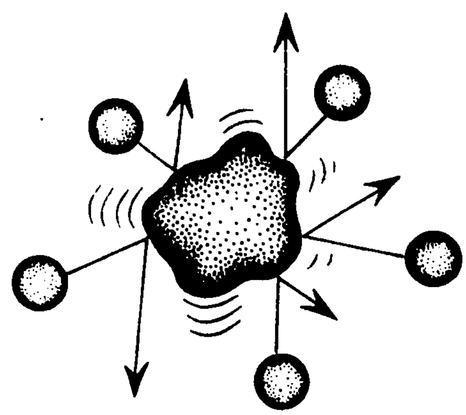
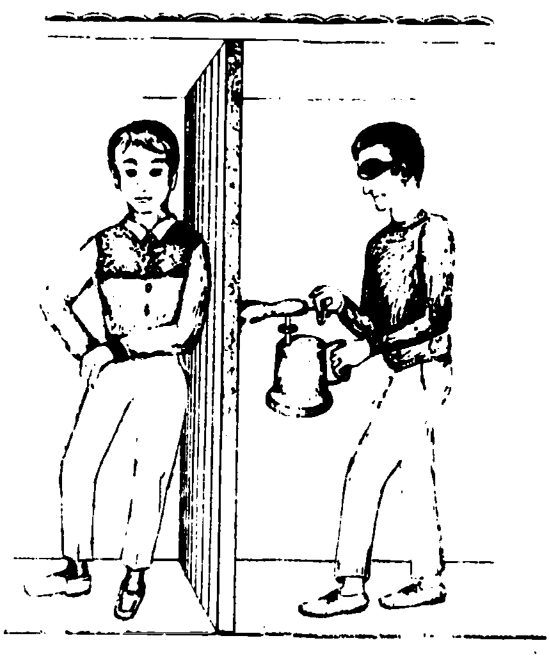


Figure B.1

B. 3. - RELEVANCE OF BROWNIAN MOTION TO TEMPERATURE

If it were practical to do so, we could increase the temperature and observe an increase in the Brownian motion of the smoke particles. From this observation we might infer that the smoke particles move faster when the air is warmer because the air molecules are moving



faster. We might correctly guess that the temperature is related to the random motion of molecules -- that is, when the temperature of a substance is increased, the random motion of its molecules is likewise increased.

C. - SOME FAMILIAR PHENOMENA AND THEIR EXPLANATIONS

C. 1. - HEAT CONDUCTION

Say that a friend of yours is leaning against the outside of a metal shed. You are inside with a blowtorch. You put the flame near the wall. There is a pause. Suddenly you hear your friend cry out. What has happened? Does the series of conversions below represent what took place?

radiant heat from the flame → higher random motion of the molecules of the wall → higher random motion of your friend's molecules

It is this increase in agitation of the molecules to which the pain-sensitive nerves in our bodies react.

Let's examine part of this conversion in greater detail. The wall is composed of molecules which have a certain amount of random motion at room temperature. When the heat of the flame reaches the surface, it is converted into energy of motion in the surface molecules. Therefore, they vibrate more energetically and interact with their neighbors. The simplest way to think of it is that the faster molecules "bump" neighboring molecules transferring this extra motion of vibration. By this molecule-to-molecule transfer of energy, the far surface of the metal also becomes hot. This movement of heat from molecule to molecule is the process of heat conduction, with which you are already familiar.

See Chap. I, C and C.2.

Materials and Equipment

set of bromine tubes
2 styrofoam cups
dry ice
burner fuel
4 large clamps
white paper or cardboard (backing for bromine tubes)

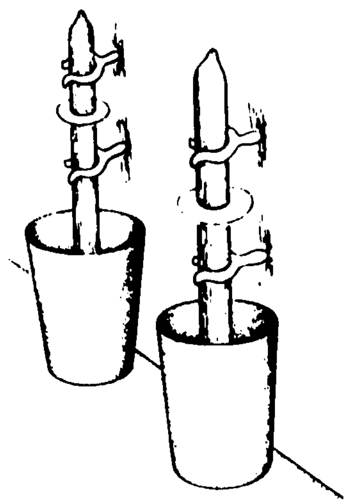


Figure C.1

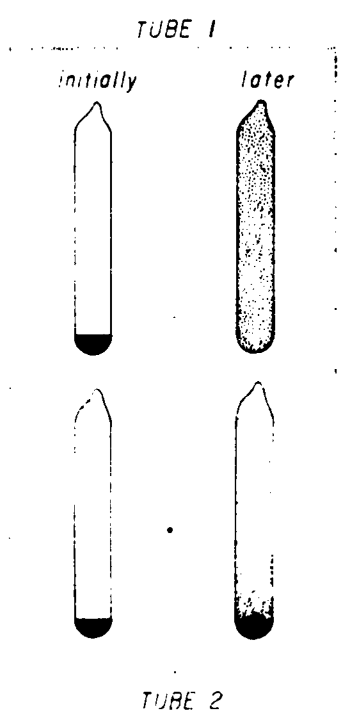


Figure C.2

C.2 - Demonstration: DIFFUSION

Bromine is a red-brown colored material which is a gas at ordinary temperatures. When it is cooled to the temperature of dry ice it becomes a solid.

The figures show two sealed glass tubes which have been initially cooled at one end in a bath of dry ice and alcohol. One of the tubes contains bromine and air. The other contains bromine and (almost) no air. When the tubes are allowed to warm up the bromine will eventually reach the far end of the tubes because the bromine molecules are in motion. We may describe this by saying the bromine <u>diffuses</u> throughout the tube. Observe this phenomenon in the classroom. What is the difference in behavior between the two tubes? Can you explain this difference? How long does it take for the gas color to become uniform? Why is it that, although the molecular motion is presumably random, there is definite direction in which the bromine goes? Perhaps the following discussion will help you answer some of these questions.

Brownian motion also gives us a clue to understanding the process of diffusion. A smoke particle is several million times as heavy as an air molecule but, qualitatively speaking, it moves around like an air molecule. If you look through a microscope at some smoke particles in air, you will see that the smaller particles have more erratic motion than the larger particles. Not only are the air molecules several million times smaller than the smoke particles, but they also are moving much faster, on the average, than the smoke particles. Nevertheless, their two motions are similar. We call such motions "random walks." You can imagine a random walk this way. Spin the arrow on a game spinner, then take a step in the direction in which the arrow points. Now spin the arrow again, taking a step in the new direction, etc. Such a process would not be very efficient for getting anywhere. Your path might look something like this:

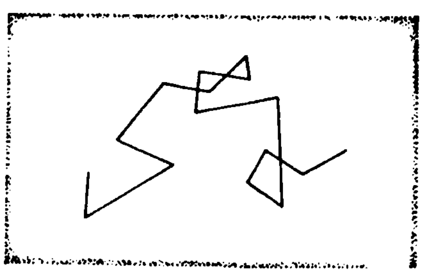


Figure C.3

After a long time you would probably be far from your starting place. Smoke particles move about in a similar way when air (convection) currents are eliminated. A particle would

The air molecules will not be moving millions of times as fast as the smoke particles. Since the average speed is only inversely proportional to the square root of the mass, the air molecules will be moving only thousands of times as fast as the smoke particles.

Our random walk model is not perfect since the size of the steps the molecules take also varies. If any students are bothered by the model, you could easily extend it by having the walker spin two arrows. One will determine the size of his step and the other will determine the direction. Random walk problems are important in statistics.

move in one direction with constant velocity until it is bumped by an air molecule which would cause it to move in another direction, etc. Each smoke particle would have a different path. After a time any given pair of particles would probably be farther apart. By this process, called diffusion, an initially concentrated wisp of smoke gets spread out. By the same process, molecules from an open bottle of perfume will diffuse throughout the room. The perfume will diffuse more rapidly than smoke because the smaller perfume molecules "take larger steps" and take them more rapidly than the smoke particles do. However, if diffusion alone were occurring, it would take at least an hour for the perfume to cross the room. We know that the odor (molecules) crosses the room in minutes; this is the result of air currents.

By chance, two smoke particles might be closer together after a long time, but on the average they would be farther apart.

The teacher might open a bottle of perfume or other aromatic substance at this point and have the class notice the diffusion and convection effects. Let each student raise his hand when the smell reaches him.

In the bromine tube demonstration the molecules are elastic like billiard balls. Random collision with the air molecules cause each molecule to execute a random walk, as discussed. The molecules spread out due to chance. When much air is present in the tube, the steps in the random walk will be small. If no air were present, some molecules would travel the length of the tube in one step.

We have seen that the molecules of a gas are in random (chaotic) motion. What about the molecules in a liquid? We can do a demonstration similar to that of the bromine tubes using two liquids of different colors. Water and a blue copper sulfate solution are good choices. Eventually the two liquids will diffuse into one another completely, although

To prepare this add 100 ml H_2O to a graduated cylinder. Then add an equal quantity of nearly saturated $CuSO_4$ solution through a long, narrow tube extending to the bottom of the graduate.

An effective demonstration of diffusion in a liquid is to drop a few crystals of potassium permanganate into the process may take months. Would you agree that the molecules in a liquid are in motion?

a large test tube or a flask and to leave it undisturbed.

C. 3. - EVAPORATION

What about the molecules on the surface of a liquid? Do they go anywhere? As a matter of fact from time to time one of them gets going fast enough to leave the liquid and enter the space above it. In a sense it "diffuses" from the liquid space into the gas space--some liquid becomes vapor. This is of course what we mean by "evaporation." Eventually the puddles in the street after a rain dry up--they evaporate. At the boiling point of a liquid there is a more extreme case. The change from liquid to gas takes place throughout the liquid, not just on its surface.

Finally we might ask about molecular motion in a solid. Molecules do not easily leave the surface. But it is clear that they are in motion. Otherwise how could a solid such as the electric immersion heater shake up the molecules of the water in which it is placed?

Exercises for Home, Desk, and Lab (HDL)

(1) A typical atom is about 10^{-8} cm in diameter. If we were able to magnify the size of an atom until it appeared to be 1 cm across, roughly how large would a tennis ball be on the same scale? The dia. of a tennis ball = 8 cm.

(1) approximately: size of ball

$= 8 \text{ cm} \times 10^8$
$= 8 \times 10^6$ m
$= 8 \times 10^3$ km
= 5,000 miles, almost the size of the earth.

(2) When bromine is placed in an evacuated tube the color seems to spread immediately throughout the tube. What does this tell you about the speed of bromine molecules?

(2) Their speed is more rapid than can be measured by the eye.

(3) We learned that the higher the temperature, the greater the Brownian motion, because the higher temperature increases the speed of the air molecules. Discuss the following:

(a) The molecules of a gas are colliding. If they are heated (go faster), do they collide with more violence?

(b) Is there any limit to how much heat you can add?

(c) Will anything happen to the molecules as they collide harder and harder?

(d) Is there any limit to how much heat can be withdrawn from an object?

(3) (a) Yes

(b) No, unless one insists on retaining the original molecular conformation.

(c) Yes. Ultimately dissociation and ionization can be expected.

(d) Yes, since an object has only a finite quantity of internal energy.

(4) Suppose that smoke particles are placed in a chamber containing compressed air. How will the Brownian motion differ from that seen at normal air pressure? Suppose the smoke particles are placed in a partial vacuum. How will their motion appear? In complete vacuum?

(4) No specific answers are presented. The aim of these questions is to stimulate the student to use his understanding of Brownian motion to rationalize his answers.

(5) In a tightly sealed bottle partly filled with liquid why doesn't all the liquid evaporate?

(5) Eventually as many molecules enter the liquid from the air space as enter the air space from the liquid The air space is said to have become "saturated."

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
A. Heat and energy							
A.1 Types of energy							
B. Energy conversions							1, 2, 3, 4, 5, 6
			B.1 Heat to electricity				
	5 Days		B.2 Conversion of electricity to heat and light				7, 8
			B.2.a. Electricity to heat and light				
B.3 Expressing electrical energy							
B.4 More conversions							9, 10, 11, 12, 13, 14
	3 Days	B.5 Experiment or Demonstration: Heat to potential energy					

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
B.6 Calculating gravitational potential energy							
		B.7 Potential energy to heat					
B.8 Kinetic energy--mechanical energy			B.9 Conversion of mechanical to electrical energy				
C. Mechanical energy among the atoms							
	2 Days	C.1 The pendulum					15
			C.2 Spring potential energy				16

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
C. 3 The "bed-spring model"							
C. 4 Specific heat	1 Day						
C.5 Heat of vaporization							18, 19
Heat of fusion							20
D. Chemical energy	2 Days						
		D.1 Exo-thermic and endothermic reactions					
D.2 Chemical changes and energy transfer							
D.3 Cell respiration							

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
D.4 A first look at the mouse data	2 Days		2 day estimate if this time is used for experimental designing of future mouse work.				
		D.5 Chemical and electrical energy					
			D.6 The storage battery				
D.7 Electricity, light, and life	2 Days					"Electric Fishes" <u>Scientific American</u> Oct. 1960 "Electricity in Plants" <u>Scientific American</u> Oct. 1962	

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
E. Conservation of energy The first law of thermodynamics	1 Day						

Chapter III: ENERGY

A. - HEAT AND ENERGY

You have been studying and working with the various aspects of the phenomenon called heat. It is important to realize, however, that heat is just one form of a more general concept known as energy. You have learned that heat can be measured and expressed in numbers (quantified) and that under certain conditions the total amount of heat in a system does not change (conservation of heat). Likewise, as you will see, all types of energy can be quantified, although the units may be different for different forms. In addition, in this chapter you will become familiar with the idea that the total amount of energy involved in <u>any</u> phenomenon always remains the same, i.e., energy is conserved. The energy may disappear in one form but it always reappears in another form. The unit expressing one form has an equivalent value in another form; they can be converted one into the other, just as units of length can be converted from inches to feet. Moreover, all energy is ultimately convertible to heat and all energy units can be expressed in terms of calories.

See Chap, I, sec. D.2.

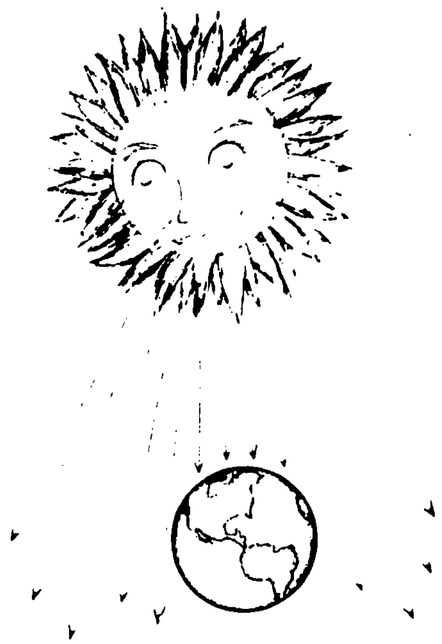


Figure A.1 The sun radiates energy, some of which the earth receives in the forms of light, heat, etc.

A.1 - TYPES OF ENERGY

Energy is very difficult to define simply, so let's discuss instead what it can do; this will be an operational definition.

Heat can travel from the sun to our earth across the emptiness of outer space just as do light, ultraviolet radiation, x rays, etc. These forms of energy are spoken of as radiant energy.

We previously saw that raising the temperature of an object gave its molecules greater movement. The heat energy was absorbed in the object and showed up as increased molecular motion. By getting its molecules all "hot and bothered" (more energetic), heat can not only boil water but can also be used to move the rotor of a gas turbine. From the other point of view, heat can arise from an object in motion. Try rubbing your hands together as hard as you can. Did your palms get hot or not? Did you ever slide down a rope? Can your skin be burned in this manner? Maybe there is a kinship between heat and light, ultraviolet radiation and x rays, just as there is between heat and the kinetic energy of moving objects. (The root of the word "kinetic" comes from the Greek language. The "kine" of "kinetic" and the "cine" of "cinema"--motion picture--have a common root in the Greek word of "motion.") The scientific worker recognizes all these as different aspects of energy.

Comment on the dichotomy of meanings of "heat."

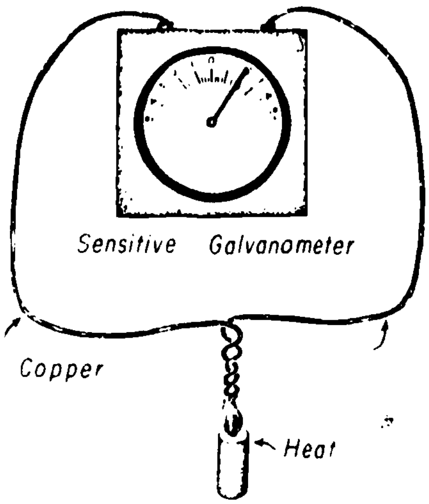
B. - ENERGY CONVERSIONS

Such apparently diverse items are lumped under the single family name of energy because they can be changed--converted--from one into the other: heat to light; light to chemical energy; nuclear energy to heat; motion energy to heat. Often these conversions are reversible. Let us become familiar with several energy forms by observing these conversions.

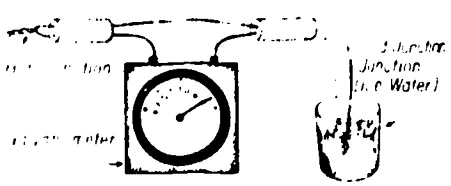
B.1 - Demonstration: HEAT TO ELECTRICITY--THE THERMOCOUPLE

Materials and Equipment
galvanometers
heat sources
copper and iron wires
Optional: constantan
ice

Take a strand of copper and a strand of iron wire and bare the ends if they are insulated. Arrange them as shown in Figure B.1.



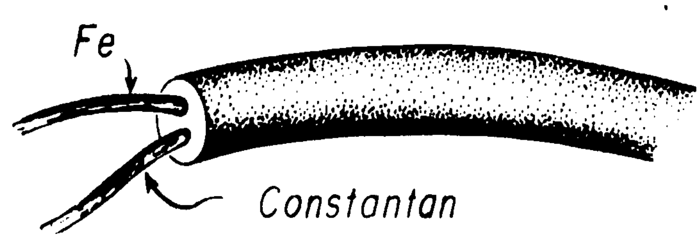
If you have iron constantan or copper constantan available, you may wish the students to arrange the experiment this way:



Better results can be achieved with this sort of arrangement as compared with the simpler one shown above.

An end of the copper wire is twisted together with an end of the iron wire and the other two ends are connected to a galvanometer. What happens when you heat the junction of the two wires? You notice that electricity flows in the circuit. Will it continue as long as you keep heating? What happens if you heat it slightly as compared to heating it intensely? Immerse the junction in ice. What results?

It is interesting to note that near the beginning of this century this type of converter was used experimentally to power telegraph systems. In recent years we have seen a number of pictures and references in the press about radio for people living in primitive situations such as Siberia or the Australian Bush. The radios are powered by a device placed in the heat from a kerosene lantern. In future years the sun's rays may be used to produce electricity for your home in a similar manner.



If the galvanometer used in the thermocouple experiments or demonstrations is not sufficiently sensitive (0-100μamp) the deflections will be hard to see.

Demonstrations indicated in the text materials should actually be demonstrated whenever possible. Do not depend on the reading to help the student learn.

B.2 - CONVERSION OF ELECTRICITY TO HEAT AND LIGHT

Materials and Equipment

power source
ammeter
rheostat
light bulb in socket

A reverse of the above conversion is demonstrated by the apparatus shown in Fig. B.2. Begin with the rheostat turned so that no current is flowing. The ammeter (an instrument which measures the flow of electricity) reads zero. Next turn the rheostat so that a bit of current flows, but do not light the lamp. Can your fingers detect heat coming from the bulb? If so, then you are witnessing this conversion:

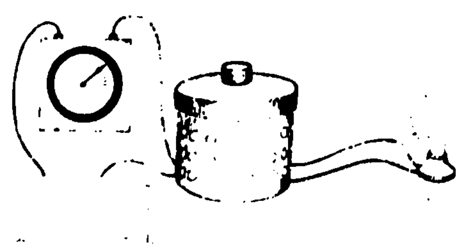


Figure B.2

Electricity $\longrightarrow$ Heat

where the arrow $\longrightarrow$ means yields, produces, or converts into.

Now turn the rheostat slowly to higher and higher settings. Light is now being produced in addition to heat.

Electrical Energy $\longrightarrow$ Light and Heat

First color to appear should be a reddish color, changing to orange, yellow and possibly white.

What color was first to appear? As the current increased, did the color remain the same?

B.2.a. Demonstration: ELECTRICITY TO HEAT AND LIGHT

Materials and Equipment
light bulb
socket
clamp
ringstand
timer (clock)

It is interesting to note that most of the electrical energy given to a light bulb is turned into heat. Lighc bulbs are better "heaters" than "lighters." They are often used to keep chicken houses and incubators warm and are sometimes placed near water pipes that are in danger of freezing in very cold weather.

We buy bulbs by wattage--50 watt, 75 watt, 100 watt, etc. This wattage is a measure of the rate of their energy output when plugged into a household circuit.

In a given time does a 100 watt bulb produce twice as much energy as a 50 watt bulb? What would you expect the ratio to be between a 100 watt bulb and a 75 watt bulb? What would you expect the ratio to be between a 150 watt bulb and a 75 watt bulb? Consider other combinations.

In principle one would expect a 100 w bulb to produce twice as much energy as a 50 w bulb and a 150 w bulb three times more energy than the 50 w bulb.

CAUTION: Do not touch the bulb, beaker or water while the apparatus is plugged in.

Student groups should not carry out this procedure; it should be done as a demonstration only.

Suspend the socket upside down so that the bulb can be lowered into or raised out of the water. Do not turn on the bulb and then lower it into the water. The hot bulb will break as one would expect. The bulb is lowered into the water at room temperature and only then turned on. It is also removed from the water only after being turned off.

The plug of the apparatus can be used as a "switch." Only plug it in after the bulb is in position. Turn off the light by pulling the plug. In this fashion the demonstrator's hands are not near the bulb and water. Do not touch the bulb--beaker--water system while the apparatus is plugged in.

Lower the cool bulb into the water until only about 1.5 cm of glass remains out of the water. A ringstand and clamp can be used. Notice that the light from the bulb seems to come through the water unimpaired. But if you hold your hand near the beaker, you cannot detect heat escaping. Most of the heat must remain in the water.

Sample Calculations:

For the 100 watt bulb using 800 ml of water:

$$\text{heat (cal)} = \text{mass of water} \times \text{sp. heat of } H_2O \times \text{temp change}$$

$$\text{heat} = 800 \text{ g} \times \frac{1.0 \text{ cal}}{\text{gram-}^{\circ}\text{C}} \times 4.1^{\circ}\text{C}$$

heat = 3280 calories.

The experimenter estimates this to have an uncertainty of ± 50 calories.

The best procedure here is to begin with the water to be heated at 1-2° C below the room temperature. The final temperature will be just above room temperature. This procedure will equalize the heat losses and gains from the room.

Do not jar the table or beaker during the heating. Water splashed up onto the hot-dry exposed part of the bulb could cause it to crack.

The data table below is blank and should be left blank. But the class under the teacher's direction may gather a similar set of data. Use a 1000 ml beaker with 800 ml of water if regular household bulbs are used. We suggest a heating period of four minutes.

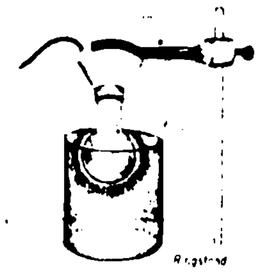


Figure B.3

Bulb	T_1 (°C)	T_2 (°C)	Calories Produced in Water
60 W			
75 W			
100 W			
150 W			

Sample set of data for demonstration experiment:

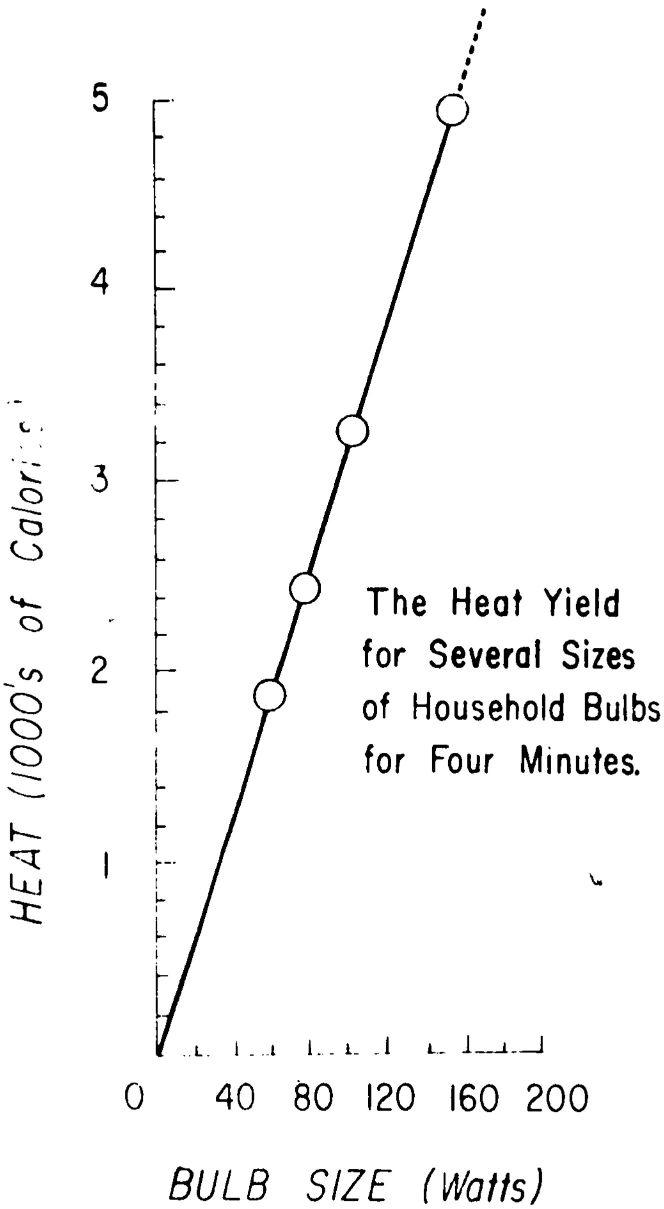
Bulb	T_1 (°C)	T_2 (°C)	*Calories Yielded*
60 w	*24.7*	*27.0*	*1840 ± 50*
75 w	*25.2*	*28.3*	*2480 ± 50*
100 w	*24.9*	*29.0*	*3280 ± 50*
150 w	*23.0*	*29.2*	*4960 ± 50*

B.3 - EXPRESSING ELECTRICAL ENERGY IN UNITS

In the labeling of light bulbs what does the designation "watts" really mean? It is a way for the manufacturer to let the buyer know how much electrical energy the bulb will put out over a period of time. The basis of this designation is a very widely used unit of energy called the <u>joule</u>; for every watt, a light bulb converts one joule of electrical energy each second. In other words, a joule of electrical energy is used up each second for each watt in the designation of the light bulb; the same amount of energy appears as light and heat. How many joules are converted by a 50 w bulb each second? How many joules are converted each minute by a 50 w bulb?

50 joules

Energy = (60 sec)(50 joules/sec)
= 3000 joules



[illegible] bulbs used [illegible] [illegible] bulbs taken at random from a grocery store shelf. They were immersed [illegible] at 1.5 cm from the metal base.

A joule represents a smaller amount of energy than a calorie. It is important however that you realize that they both represent energy; the difference is that they are not the same size unit and that the calorie is more usual when referring to heat energy and the joule is more popular whenever most other forms of energy are concerned. (It is somewhat like the fact that yards are a more common unit when measuring the distance from one place on a football field to another, whereas inches are more common in measuring the distance between the top of your head and the bottom of your feet.)

Stress that calories are "bigger" than joules. To interconvert calories and joules it may help to remember that for a given amount of energy the number of joules is always greater than the number of calories. Therefore:

$$\text{Joules} = (\text{Calories})(4.2)$$

$$\text{and Calories} = \frac{\text{Joules}}{4.2}$$

To convert from joules to calories we need only to know how big one unit is compared to the other. For instance we could do a very careful experiment in which a known amount of electrical energy was converted completely to heat (such as in the immersion heater you used in the chapter on heat). The result you would find is that for every calorie produced approximately 4.2 joules of energy is needed; therefore, 1 calorie = 4.2 joules. (If all the energy of a 100 watt bulb could be converted to heat, how many calories would be produced in 10 seconds?) Of course any kind of energy can be

$$\text{Energy (joules)} = (100\ \text{joules/sec.})(10\ \text{sec.}) = 1000\ \text{joules}$$

$$\text{Energy (calories)} = \frac{(1000\ \text{joules})}{(4.2\ \text{joules/calories})} = 238\ \text{calories}$$

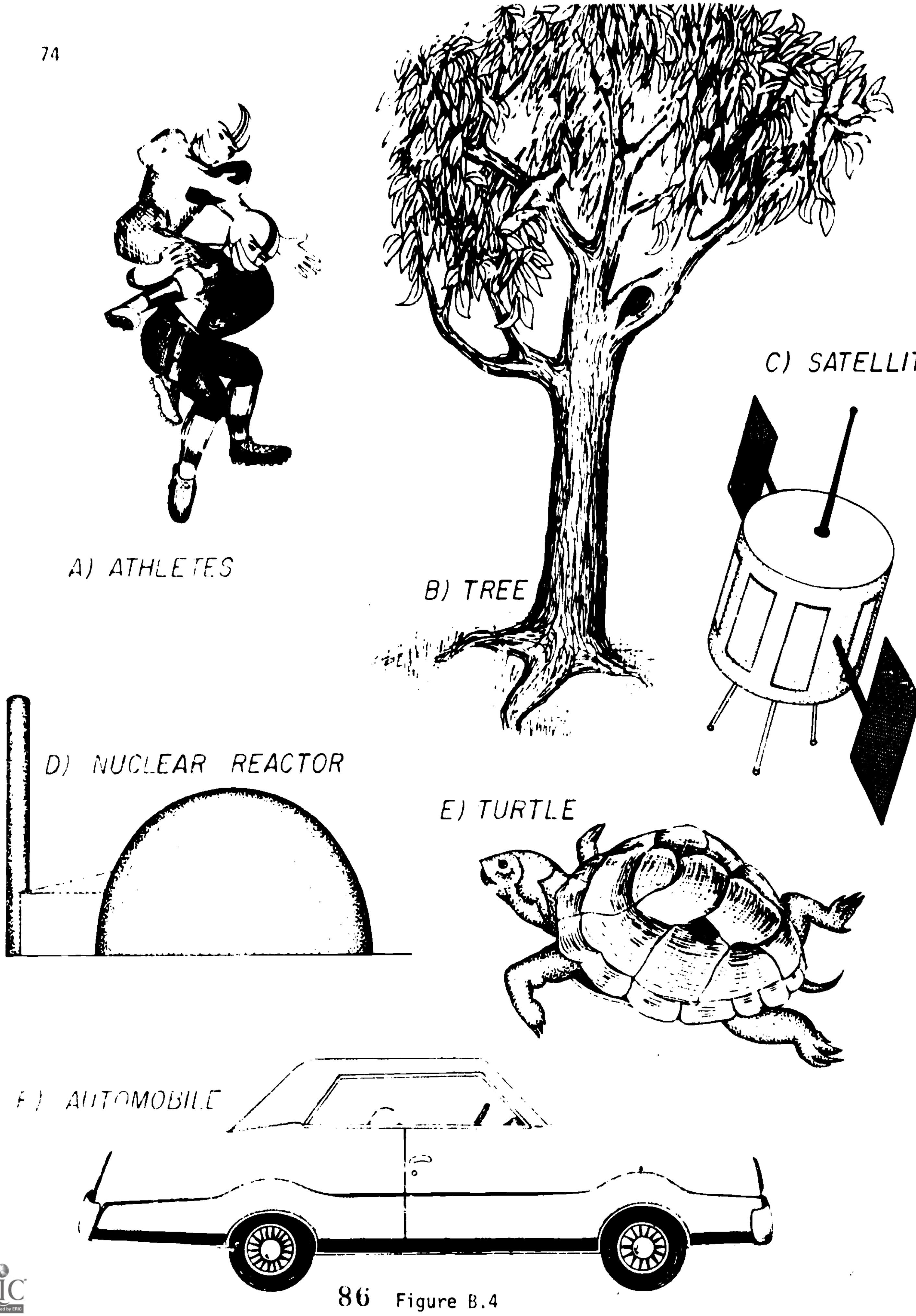

A) ATHLETES
B) TREE
C) SATELLITE
D) NUCLEAR REACTOR
E) TURTLE
F) AUTOMOBILE

Figure B.4

measured in either Joules or calories; sometimes one unit is preferred whereas sometimes the other.

B.4 - MORE CONVERSIONS

If electricity can be turned into light, then a natural question follows: can light be turned into electricity? In recent years we have heard much about solar cells and batteries. Our space vehicles make extensive use of them. Figure B.5 indicates what a single cell might be like, while Figure B.4.c on the previous page indicates how a space vehicle may have large panels containing a great many cells on each panel. Each single cell yields only a minute current; large areas covered with these cells are necessary to get useful amounts of energy. We do not need to discuss the inner processes of the solar cell at this time in order to appreciate that it involves the following conversion:

Light $\longrightarrow$ Electricity

It is important to think of the solar cell as an energy converter. Several kinds of these light-to-electricity converters have been developed and find extensive use in photography and other activities where measurement of light is important.

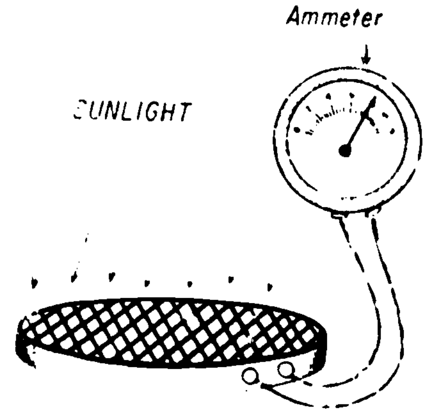


Figure B.5
A Solar Cell

A digression into solar cell theory at this time would not be time well spent. However, if a solar cell is available, it should be demonstrated.

We have shown that the electricity-to-light conversion can be reversed. What about electricity-to-heat conversion? Can it also be reversed?

Materials and Equipment
125 ml Erlenmeyer flask
rubber stopper
plastic syringe
tripod
heat source
500 gm. weight
glycerine

This demonstration is optional.

B.5 - Experiment or Demonstration: HEAT TO POTENTIAL ENERGY

Set up the apparatus sketched below.

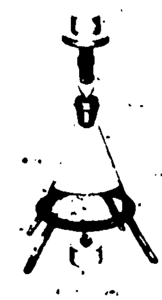


Figure B.6

Make sure the apparatus is well clamped to prevent tipping over and that the total weight is supported by the stand. The syringe should be lubricated with glycerine. You will find it doesn't take much heat to raise the weight.

The word "potential" is an appropriate choice here. If you say that a person is "potentially" a good artist, you mean that "stored" inside of him are the necessary talents to become a fine artist. Similarly, potential energy is "stored" energy.

The weight in its higher position is thought of as having more energy than in its lower position. If the weight were dropped from its higher position to a platform set at its lower position it would produce some heat. The weight has in its upper position the potential (unused ability) to produce another form of energy, such as heat. Thus it is said to have potential energy. In particular, since it was given this energy by being pushed up against the pull of gravity and will give up its energy when allowed to fall with gravity, it is said to have <u>gravitational potential energy.</u>

How did the energy actually get transferred to the weight? We can look at it this way: the air and water vapor molecules in the flask by virtue of their heat energy were constantly bombarding the bottom of the plunger, thus causing it to move up. The plunger moved up because energy was transferred from the gas (molecular motion) to the plunger. The gas received the energy from the alcohol lamp, which in our system was the initial source of energy. Most of the missing heat energy from the initial source can be accounted for by the increased potential energy of the weight.

B.6 - CALCULATING GRAVITATIONAL POTENTIAL ENERGY: ANOTHER EXAMPLE OF A CONVERSION

There are several things that must be taken into account when figuring out the amount of energy stored up by a raised weight. First of all, it must be true that two identical weights when lifted to the same height will have twice the potential energy of just one of these weights. (Can you justify this

Each weight, when falling, will generate the same amount of heat as was originally stored.

statement?) Hence the energy is proportional to (depends directly upon) the mass raised, m. Secondly, the higher the weight is raised the greater is the potential energy. In the last experiment, for instance, it would take twice as many pushes by the moving gas molecules to push the cylinder up 2 mm as it would take to move it 1 mm. Twice as much heat would have been converted to potential energy. So energy stored depends directly upon the height raised, h. Finally, the stronger the gravitational pull, the harder it would be to raise the weight. Not as much potential energy would be given to a rock lifted from the surface of the moon as would be given to a similar rock lifted the same distance from the surface of the earth. In calculating potential energy, this fact is taken into account by a number proportional to the gravitational attraction, g.

The units of g are actually meters/sec^2. It would take more discussion of mechanics to show the result is in joules. It is reasonable to consider g to be a proportionality constant with units joule/Kg-meters.

The complete formula is thus:

Potential Energy = mgh

When m is expressed in kilograms and h is stated in meters, the units of energy will turn out to be in joules. The value of g for the surface of the earth is 9.8 $\frac{\text{joule}}{\text{Kg-meter}}$.

If a 1.0 kilogram weight were raised 0.3 meters by the piston in the last experiment, how much potential energy was it given? How many calories were taken from the gas to do this?

Energy (joules)

= (1.0)(0.30)(9.8)
= 2.9 joules potential energy

Energy (calories)

= 2.9/4.2
= 0.7 cal

B.7 - Experiment: POTENTIAL ENERGY TO HEAT - THE "FALLING STUFF" EXPERIMENT

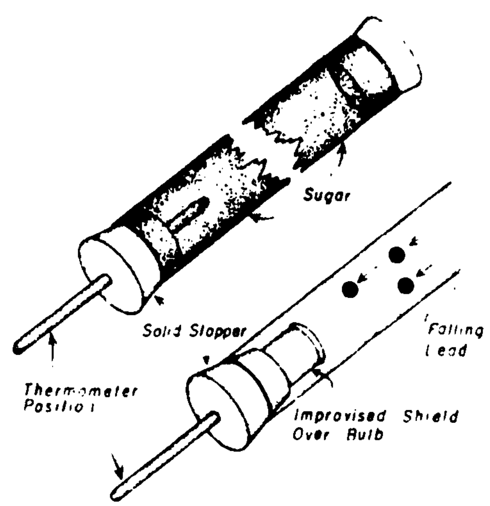
Obtain a mailing tube about 1 meter long and 3-5 cm in diameter (the exact dimensions are not critical). Use large stoppers to close the ends. Make a small hole in the mailing tube 2-3 cm from one end so that a thermometer can be inserted from the side. Put a cup or two of lead shot into this apparatus. With the lead at one end, take the temperature of the lead. (It should be very close to room temperature.)

Determine this temperature, remove the thermometer, and cover the hole with your finger or other suitable instrument. Rotate the tube so that the shot is raised to the upper end and falls the length of the tube. Repeat this action rapidly until the lead has fallen fifty times the tube length. Record the temperature of the lead. Repeat. What is the temperature after one hundred falls? One hundred fifty falls? Two hundred? Two hundred

Materials and Equipment
cardboard mailing tube about 1 m in length
stoppers to fit ends
lead shot, 1 c. or more
thermometer
thermometer shield

The apparatus used by the students is simple--a mailing tube, the size not being a critical factor. The data discussed here was gathered from measurements in a cardboard tube with a 2-inch inner diameter and a length of approximately 42 inches.

When sugar is being used, the thermometer need not be protected from the falling sugar. The lead shot would probably break the thermometer and some variation needs to be used. The diagrams below indicate methods.



During the turning of the tube, a finger can be used to close the thermometer hole. Be sure to wait after inserting the thermometer for the thermal equilibrium to be reached, or erroneous (low) temperature readings will result.

The data in Table A represents data from one cup of sugar being dropped down a cardboard tube which was just short of 4 feet long.

Table B refers to falling lead shot.

TABLE A (sugar) Falls	Temp (°C)	TABLE B (lead shot) Falls	Temp (°C)
0	23.5	0	23.0
0	[illegible]0.1	50	24.1
50	23.7	100	25.0
100	23.9	150	25.3
150	24.0	200	25.7
200	24.1	250	26.0
250	24.2	300	
300	24.2		

Room temperature = 23.4° C.

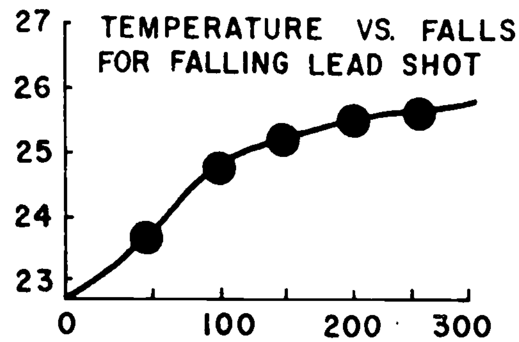
Students may be interested in the tendency of the data to level off. What is your extrapolation for the maximum temperature in the temperature vs. falls for lead shot on the graph? It should be 26.3° C. Apparently this maximum temperature is reached when the heat gained from the action of falling is balanced by the heat lost by conduction through the walls.

fifty? Three hundred? Plot a graph of temperature versus number of falls. What caused the temperature change? What would have been the results if lead had not been the falling material? Suppose it had been some other solid like sugar or even a liquid such as water?

We might try to calculate what temperature rise we should expect. For instance, for each fall of the lead shot the temperature rise would be

$$\begin{pmatrix}\text{Change in}\\ \text{T per fall}\end{pmatrix} = \begin{pmatrix}\text{Potential energy}\\ \text{lost by lead}\end{pmatrix}\begin{pmatrix}\text{specific}\\ \text{heat of lead}\end{pmatrix}$$

The discussion of section B.6 tells us how to calculate the potential energy lost by the lead. In calories this is simply $\left(\frac{mgh}{4.2}\right)$, where m is the mass of the shot, h is the length of the tube, and g has the value 9.8. Calculate the expected rise in temperature for various



$$\Delta t = \frac{cal}{(\text{mass in grams})(\text{Specific heat})}$$

Since Cal = Joules/4.2

$$\Delta t = \frac{\frac{(\text{Mass in kilograms})(g)(h)}{4.2}}{(\text{Mass in grams})(\text{Specific heat})}$$

$$\Delta t = \frac{(9.8)(h)}{(4.2)(0.03)(1000)}$$

$$\Delta t = 7.7 \times 10^{-2}\ h$$

Calculate the expected rise in temperature etc.

Heat generated goes to heating of apparatus, conduction, convection. Note also the shot may not fall through all of h.

Losses due to conduction should increase with the number of falls hence the temperature curve should flatten out.

numbers of falls, and plot it on the same graph as your experimental results. Apparently not all the heat generated is going to the lead. Can you suggest where else it goes? Does your suggestion help explain your data?

B.8 - KINETIC ENERGY AND MECHANICAL ENERGY

When doing the "falling stuff" experiment did you stop to think of exactly when the potential energy gets converted to heat? Consider some shot falling the length of the tube. When it is nearly at the bottom of the tube but has not yet hit, where is the energy? It is not in the form of potential energy to any great extent, since it is no longer very high up. Likewise it has not yet been largely converted to heat, since it is the impact with the end of the tube which "shakes up" the lead atoms and thus makes the temperature rise. The significant thing about the lead at this stage is that it is moving; we regard the lead as having energy by virtue of its motion.

Energy of motion is called <u>kinetic energy</u>. All moving objects can be thought of as having kinetic energy in addition to any other forms they may also possess. When the motion stops, the kinetic energy must be converted to other forms. Thus in the falling stuff experiment we can diagram the conversions as follows:

Potential Energy ⟶ Kinetic Energy ⟶ Heat

Both potential energy and kinetic energy are associated with the configurations (locations in space) of material bodies. The potential energy has to do strictly with positions of bodies, while kinetic energy has to do with the changes in position (motion) of such bodies. These are the essential ideas involved in basic mechanical devices such as levers, gears, pulleys, etc.--so-called simple machines. Thus both potential and kinetic energies are often lumped together under the heading of mechanical energy.

B.9 - Demonstration: CONVERSION OF MECHANICAL TO ELECTRICAL ENERGY

One more demonstration of an energy conversion will help clarify the concept better. Many high schools have small hand-cranked generators. Turning the crank takes muscular energy that rotates the crank and inner parts of the generator. As these parts spin, their mechanical energy (mechanical energy simply refers to the energy of motion of the moving parts) is converted into electricity. Holding your fingers against the wire leads will prove that this conversion is taking place. If you are hesitant, you may prefer to have a light bulb of low wattage attached in order to demonstrate that electrical energy is in the wires.

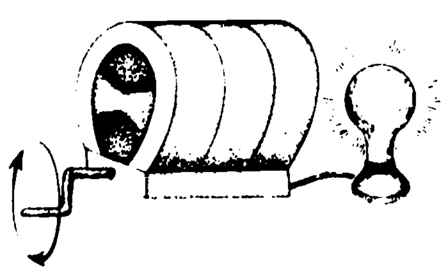


Figure B.7 - The Conversion of Mechanical Energy to Electrical

electrical energy $\longrightarrow$ mechanical energy of rotating parts

The explanation of "why" and "how" the above conversion occurs will have to wait for the latter part of our three-year course.

We have seen that a generator is a device that turns the rotational energy into electricity. What do you call the device that turns electricity into rotational motion?

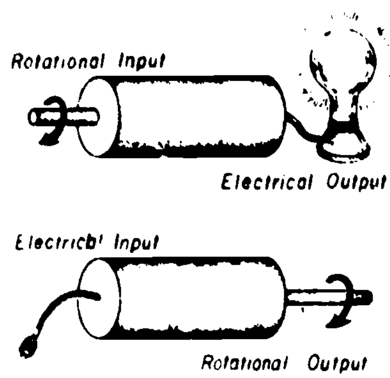


Figure B.8

C. - MECHANICAL ENERGY AMONG THE ATOMS

C.1 - CONVERSION OF POTENTIAL TO KINETIC ENERGY: Experiment: THE PENDULUM

Hang a pendulum bob by a string from a solid support (Figure C.1.a). Pull it back and release it. Note how high it goes at the opposite end of its swing and on its return to the origin point. Did the bob have as much PE when it returned to point A as when it started from point A? After successive swings? What other kind of energy besides potential energy was involved? How long until all the energy you gave it by pulling it back to the release point has been lost? What has become of it?

Now arrange a rigid rod to interrupt the swing (Figure C.1.b). Now how high does the bob swing? What about the height upon its return to A? What conclusion can you come to concerning these energy exchanges? Try putting the interrupting bar at different levels. Did

Materials and Equipment:
Lead sinker, heavy washer, or other solid
Fishing line or string

Pendulum bobs can be any fairly compact object. The string provided should not stretch. Fishing line would work well. The supports must not vibrate or wiggle. Also, if the student does the experiment before a blackboard, he could more easily note heights of swing.

If no losses occurred, it would have come back to the original point. This will, however, not happen since small frictional losses will occur during each swing.

No matter where the interrupting rod is placed, we would--in spite of frictional losses--expect the pendulum bob to return to the same place each time. If the interrupter bar is placed too close to the bottom of the swing, the pendulum length will be too short to permit simple oscillations, and the pendulum bob will wrap itself around the support.

PE → KE → PE → KE → PE → etc. ad infinitum

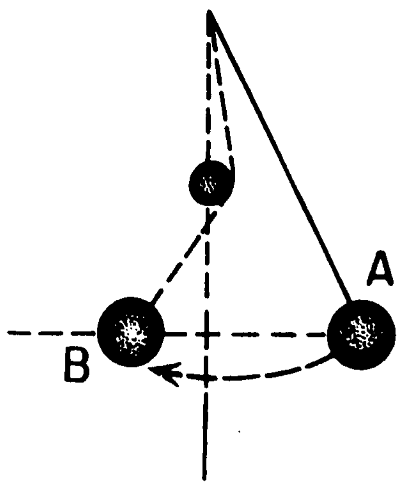


Figure C.1.b - An Interrupted Pendulum

Materials and Equipment

PSSC inertial balances
C clamps
lumps of clay

It would be best to set up the apparatus shown in Figure C.2. The PSSC inertial balance kit is the item. Do not try to use it this time to teach the relationship that it is used for in PSSC.

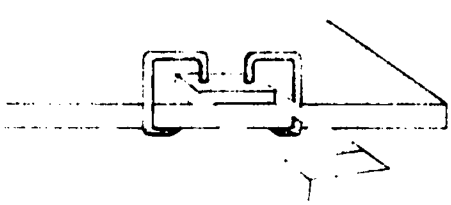


Figure C.2 - A Horizontal Pendulum

The teacher could and should set up more demonstrations like the following to illustrate the principle of energy conversions:

you also try beginning the swing at point B?

Express the energy conversions involved here by using the "→" notation.

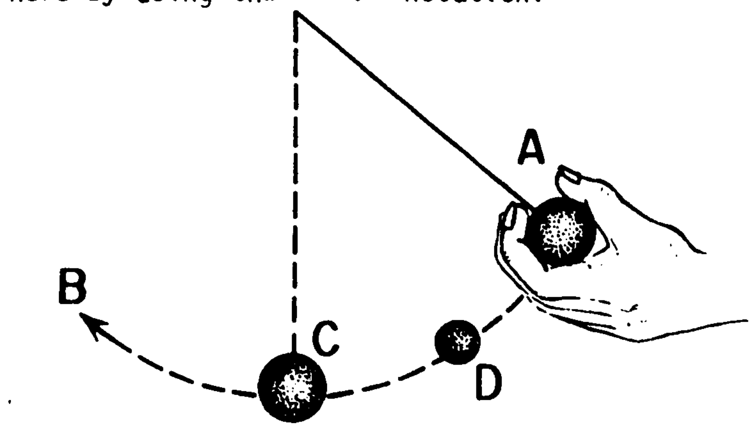


Figure C.1.a - The Pendulum

C.2 - SPRING POTENTIAL ENERGY
Demonstration: THE INERTIAL BALANCE

Figure C.2 shows an apparatus called an inertial balance. Pull it to one side and watch it swing back and forth. You can see that it is like two flexible hacksaw blades. Try adding material to its platform. C clamps can be hooked on easily. What happens to its vibration when the extra material is hooked on? Do you see a similarity to the pendulum in the previous experiment? Similarity of motion is easily seen, but maybe the differences are more striking.

The regular or gravitational pendulum could be explained by this series:

work done in lifting bob to initial point → PE (gravitational) → KE → PE (grav.) → KE → PE (grav.) → etc.

The apparatus we are watching is not lifted. When pushed sideways, the PE results from doing work to bend the spring-like metal blades.

work done in initial bending → PE (spring) → KE → PE (spring) → KE → PE (spring) → etc.

This change can repeat itself over and over in cycles for a long time. If no energy was lost, could such a vibration go on forever? Or would it? Do repeated or cyclic energy conversions occur only in non-living materials?

C.3 - THE "BEDSPRING MODEL"

Objects can have both potential and kinetic energy. In some cases, such as a mass-spring combination there is a continuous conversion back and forth between the two forms. In a large collection of such objects a certain proportion of the total energy would on the average be in the PE form and another part in KE.

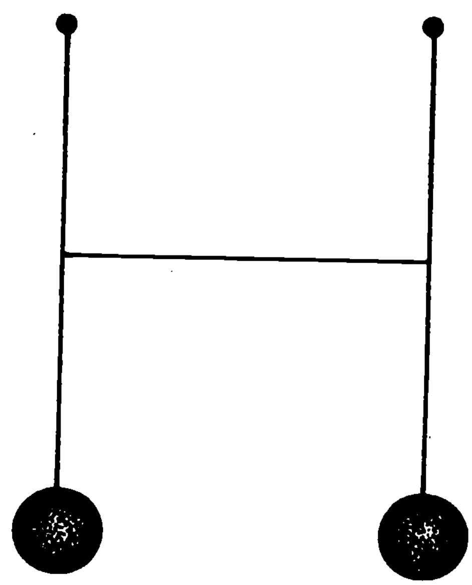
Large assemblies of atoms, such as those forming solid substances, can in many ways be regarded as a collection of masses and helical springs all interconnected. The figure should make clear why this is often called the "bedspring model" of materials. The little black balls represent molecules and the springs

(1) sympathetic vibrations between sounding boxes;

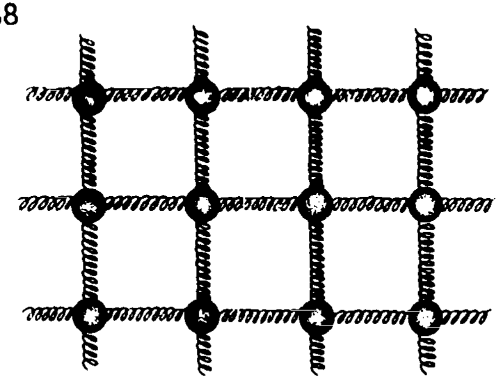
(2) a "Jolly balance";

(3) pounding a penny ("hot" money).

Consider one final demonstration--a coupled pendulum (shown below). We start one of the pendulums in motion. As time passes, you will notice that the energy is apparently passed from one pendulum to the other and back again, over and over. In many places in nature, both living and non-living, we can see such interchanges of energy from one system to another--sometimes over and over again. Recall the use of CO_2 and water in photosynthesizing plants, which synthesize glucose, and the subsequent metabolism of glucose in living organisms which results in CO_2 and water.



A coupled pendulum.



The "bedspring model." Figure C.3. Only one layer is shown here. The model should be thought of as extending in front of and behind the paper in a three-dimensional array.

represent the forces which attach them one to the other. These atoms are always in motion, jiggling to and fro from their average position. They thus have kinetic energy, and a measure of this is the temperature of the substance. However, since there are "springs" among these atoms, the substance also contains potential energy.

C.4 - SPECIFIC HEAT

What happens when we put heat into a material? Among other things the molecules increase their motion. The kinetic energy becomes greater; the temperature rises. In addition, as a consequence of the increased motion the "springs" are continuously being extended or compressed. Thus some heat energy goes into potential energy as well. Thus in a solid or a liquid, unlike a gas, when heat energy is added, not all of it goes into simply moving the molecules. For every substance, depending on just how the molecules are arranged and attached, a different amount of heat is required to raise the temperature a certain amount. When the amount of heat required is great, we say we have a high specific heat substance. When it is small, we have a low specific heat substance. Recall that in Chap. I, sec. A.3, the specific heat of water was found to be greater than that of cooking oil. Study of specific heats of materials is a powerful method which helps scientists decide how materials are constructed at the molecular level.

C.5 - HEAT OF VAPORIZATION AND HEAT OF FUSION

When pure water is boiled, the temperature stays at 100° C even though heat continues to be supplied. (You may have done this experiment during your studies in Perception and Quantification.) In fact it takes 539 cal just to evaporate 1 g of water at 100° C to form 1 g of steam at 100° C. We are now in a position to explain why a substance can take in heat without rising in temperature.

This section refers to the experiments performed in the Perception and Quantification, Chap. II, sections D.4.c. and D.4.e. The latter experiment is listed as optional. If it was not done previously, it might be done at this point.

This may partially explain why a steam burn can be much worse than a burn from boiling water.

In liquids the arrangement of the molecules is not so regular as in solids, but there are close "spring-like" associations within and among some of the molecules. When heat is added both kinetic and potential energy is increased. However, at a certain temperature molecules begin to detach themselves completely from one another. This is the boiling point. For each molecule that goes into the vapor, the attachment to the other molecules is completely broken.

It is now free and has only kinetic energy. The "spring" attaching these vaporizing molecules must be stretched out before the connection is broken. Thus during boiling, heat must be supplied which does not raise the temperature but simply provides energy necessary to break attachments and permit molecules to depart into the vapor. This heat is called the heat of vaporization. A similar effect occurs during melting of a solid. Heat is required which doesn't raise the temperature but only releases some molecular attachments so that a liquid is formed. This is called the heat of fusion.

There is a reverse situation also. When a gas condenses to form a liquid (steam becomes liquid water) heat must be removed. Molecules in the vapor rejoin other molecules to form droplets. The "springs" are remade and relaxed; potential energy is lowered. Heat is given up during the process even though the temperature does not change. For any mass of material it is the same amount as the heat of vaporization. Likewise when a liquid such as water freezes to form a solid (ice) the heat of fusion must be removed. Do you remember the freezing point experiment you did in Perception and Quantification? The flat section on your graph (cooling curve) means that at the freezing point heat was being lost to the room even though the temperature was not changing. This heat was the heat of fusion of paradichlorobenzene or napthalene.

D. - CHEMICAL ENERGY

When molecules are joined or separated during the processes of freezing, melting, boiling, etc. energy is given up or taken in. Likewise, when atoms are combined or separated to form different molecules, energy is exchanged with the surroundings. The energy which is stored in molecules after they have been "put together" from atoms is called chemical energy. Chemical energy may be released in a number of different forms: heat, electricity, light. You have already encountered several examples: peanuts, alcohol burners, batteries, etc. By the same token chemical energy may be acquired from various sources: heat, electricity, etc. We will now investigate some of these conversions.

D.1 - Experiment: EXOTHERMIC AND ENDOTHERMIC REACTIONS

Equipment and Materials:
(for each group of students)

2 250 ml beakers
thermometer
stirring rod
10 g ammonium chloride
10 g sodium hydroxide

Place about 10 grams of granular ammonium chloride into 50 ml of water at room temperature. Record the temperature before you add the ammonium chloride and then record the temperature

Use extreme caution. Warn students of the dangers involved.

every 30 seconds until the temperature levels off. What did you discover? This is an example of an endothermic chemical change. Look up the definition of the term endothermic.

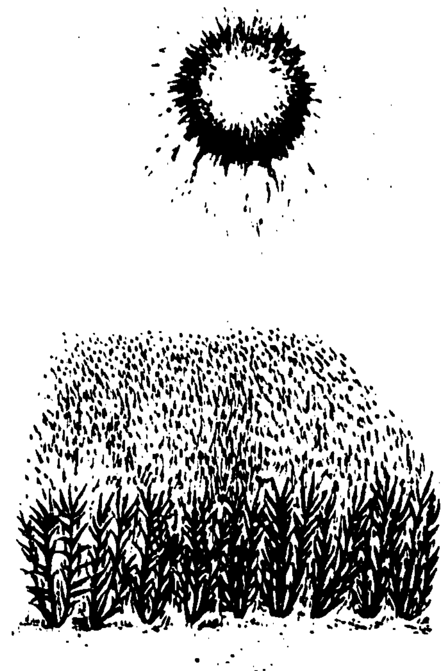
Using extreme caution, place about 10 grams of sodium hydroxide (lye) into 100 ml of water in a 250 ml beaker. (DO NOT COME IN CONTACT WITH THE SODIUM HYDROXIDE OR ITS SOLUTION.) As in the first part of the experiment, record the initial temperature and successive changes in temperature. Find the definition of the term exothermic. Does it apply to this interaction? Would you describe the burning of a fuel as an exothermic or an endothermic interaction?

Make a graph of the temperature changes versus time for each of the above interactions. Place both on the same graph. How do the curves compare?

D.2 - CHEMICAL CHANGES AND ENERGY TRANSFER

In chemical changes which take place spontaneously the new molecules usually have less chemical energy than the parent molecules. Whenever newly formed molecules have more chemical energy than was present in the parent molecules, the chemical interaction requires a continuous input of energy in the form of heat, light, or electricity. The electrolysis of water produces hydrogen and oxygen molecules which are richer in energy than the water molecules they came from. This process of electrolysis requires a continuous input of electrical energy.

Sugar is a compound rich in chemical energy. It is produced by green plants from the less "energy-rich" molecules carbon dioxide and water. This is a complex biochemical change called photosynthesis, which requires a continuous input of light energy. It is interesting to note that the production of sugar is a process which suggests a reversal of the burning of fuels. Is photosynthesis similar to the operation of the solar cell? Would you consider the green plant to be a type of energy converter? Would you agree that vegetation stores solar energy?



In photosynthesis light is converted to chemical energy; in the solar cell light is converted to electrical energy.

There is a common name for the source of chemical energy for the body: it is called "food." Let us consider briefly the processes by which living things extract and utilize the energy in food.

D.3 - CELL RESPIRATION

We get energy from food, and when we use muscle power we are making use of that energy. Consider the example of rubbing the hands together to produce heat. What energy conversions

This brief overview of photosynthesis and cell respiration might also be used as an introduction to ecology, which will be studied more extensively in Part Three.

are involved? It is something like this:

chemical energy stored in food $\longrightarrow$ energy stored in our muscles $\longrightarrow$ heat energy at the palms

Remember when you burned the peanut and measured the heat produced? Is the heat produced by rubbing your palms together generated through the same process? When you eat a bag of peanuts or a cheese sandwich, do you feel a warm "glow" all over? Of course not. Do you suppose that all those calories (how many would there be in a 90 g bag of peanuts?) are used to heat you? Not likely. How does your body use these calories? Remember that this refers to a measure of heat. Packaged calories come disguised as hotdogs, pizza, carrot sticks, and in many other forms. Some of these packages contain a lot of potential heat (calories). Why then don't you just go up in smoke?

In the sense that the heat produced by rubbing your palms together results from friction rather than oxidation, the processes are not the same. However, in the sense that the energy required to rub the palms together results from metabolic oxidation of foods (like peanuts) the two are similar.

Calories for 90 g of peanuts will have to be based on data from your class.

The clue to this is in the way the food is broken down or utilized within you--or any other living organism, for that matter. The energy tied up in that package is released bit by bit and piece by piece in a process called cellular respiration. This respiration, which refers to activities at the level of atoms and molecules, is not to be confused with the respiration which we refer to when we talk about breathing.

Cell respiration can be defined as the step-by-step release of energy from food.

Where does the energy go? Some of it does, in fact, serve as a source of heat for you. You expect to maintain your body temperature at 37° C (98.6° F) all the time. For other organisms "normal" temperature might be higher or lower than this. In song birds it is 45° C; in hamsters it is 36° C; in dogs it is 38.6° C. In each case we expect the healthy individual to maintain this temperature whether he finds himself in the arctic wastes or on a tropical island. This is just one example of the many ways in which some living systems maintain a constant condition by using energy. Do all living systems maintain a constant temperature? What determines a lizard's or fish's temperature?

Not all living systems maintain a constant temperature. Body temperature of cold-blooded animals is determined by the surrounding temperature.

Much of the energy available from cellular respiration is given out in forms other than heat, as indicated in Figure D.1. These will

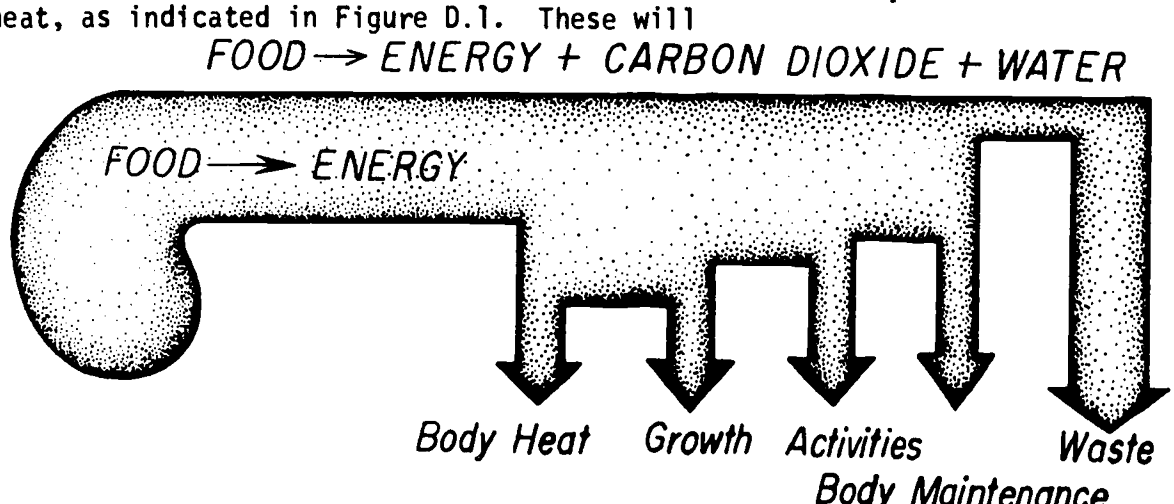


Figure D.1 - Respiration Releases Energy for use in Organisms.

In calories/hour: gardening, golfing, dancing, housework, respectively.

Cell respiration is about 40-50% efficient, as Lehninger says on page 38 of <u>*Bioenergetics*</u>.

be used for many purposes with which you are familiar, including things like energy for activities. Which would require a greater energy source--dancing or doing housework? Gardening or golfing? Is energy required when you are at complete rest?

It is interesting to note the similarity between energy use in living organisms and in gas engines. Comparing Figure D.1 and Figure D.2, observe that the two systems start with similar products--food or fuel and oxygen--and end with similar products--energy, carbon dioxide, and water.

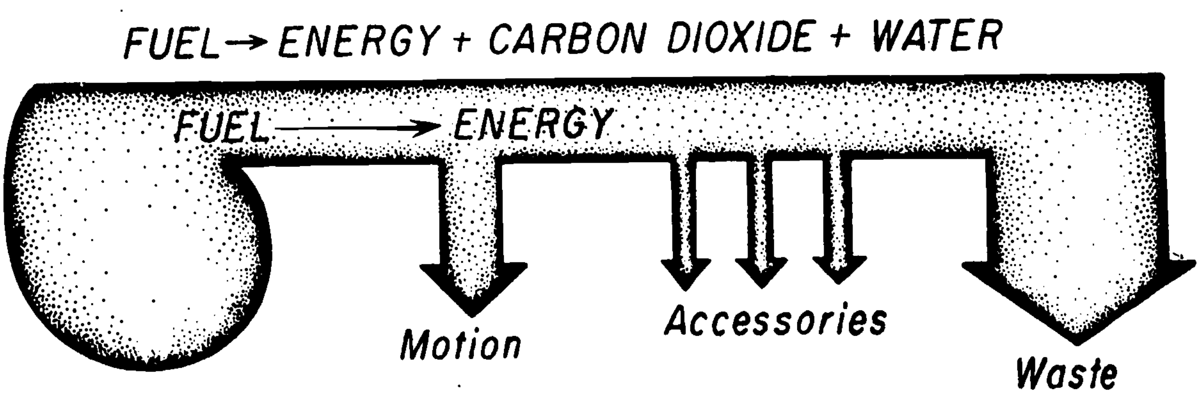


Figure D.2 - Energy Distribution from Gasoline-Powered Car

D.4 - A FIRST LOOK AT THE MOUSE DATA

In Figure D.1 one arrow points to the use of energy for growth. As we collect and study the mouse data, can we correlate energy intake with growth?

MORE ABOUT THE MOUSE DATA

One of the questions may involve the mass of the input of food and water compared with the change in weight of the mice (colony).

The student may jump to the conclusion that:

Fecal + urinal masses + change in mouse mass = food and water input mass.

The mass of urine and feces produced in 24 hours may be estimated by the following method:

a) remove all loose litter
b) weigh a dry paper towel and put it in whole as a substitute
c) one day later clean the cage as thoroughly as possible using the paper towel
d) find the change in mass of the towel; this should be close to the mass of the feces and urine produced.

In order to get at some of the above questions, the student will need to gather data on a sheet which gives him most of the following information:

a) date and time of start
b) date and time complete
c) elapsed time in hours
d) number of mice
e) mass of mice at the end -
f) mass of mice at the start =
g) change in mouse mass
h) mass of food offered -
i) mass of food left =
j) mass of food input
k) volume of water offered -
l) volume of water left =
m) volume of water input

n) *mass of dirty paper towel -*
o) *mass of clean paper towels =*
p) *mass of urine and feces*
q) *INPUT (food and water)-*
r) *OUTPUT (feces and urine =*
s) *change in mouse mass*
t) *(difference between input and output)*
u) *output is what % of input?*

If evaporation of urine is a problem, one may try to capture the urine in a test tube. Housing a single mouse on two funnels may yield better data.

Discuss the energy conversions occurring in the mouse colony. Is energy conserved here?

Conservation of mass may be difficult to demonstrate, since we have no practical means to measure input and output of gases.

Discuss problems you are having in making observations and other processes with the teacher.

Identify problems people are having with data gathering.

Settle business involving special questions you wish to ask about the mice and their food.

Discuss anticipated problems setting up graphs.

Obtain the data you need about the colony from other students.

Colony data is still being gathered. TRY NOT TO REDUCE THE SIZE OF THE COLONY YET.

D.5 - CHEMICAL AND ELECTRICAL ENERGY
Experiment: A "PENNY" BATTERY

Materials and Equipment
- *galvanometer*
- *paper towel*
- *salt water*
- *iron washer*
- *penny*
- *zinc*, *aluminum*, *copper* — *strips*
- *fresh lemon*
- *carbon rods (opt.)*

Sandwich about three layers of paper toweling moistened with salt water between an iron washer and a penny (Figure D.3). Touch the two wires from the galvanometer to opposite sides of the "sandwich." Observe the needle on the galvanometer. Try reversing the wire connections.

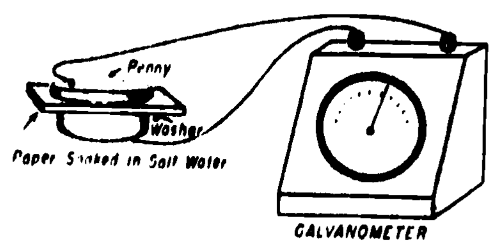


Figure D.3

You have just made an energy converter called an electrolytic cell. This is similar to the commercial "dry cell." What materials are used in a flashlight cell?

Place a strip of zinc or aluminum metal and a strip of copper into some citrus fruit (Figure D.4). Touch the wires from the galvanometer to the strips of metal and observe the galvanometer. If you can obtain a thick piece of pencil lead (carbon), insert it into the citrus fruit in place of the copper strip. What do you observe? What happens if both strips are

The commercial dry cell uses zinc and carbon as electrodes and the electrolyte consists of a paste of ammonium chloride, carbon and manganese dioxide.

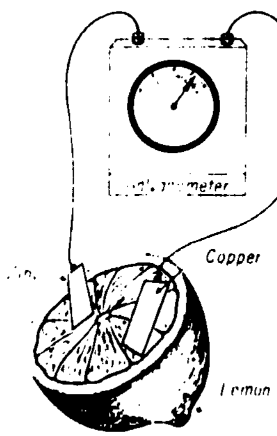


Figure D.4

In general, dissimilar metals would be expected to give rise to a galvanic action, causing a deflection of the galvanometer, while the presence of similar metals would give rise to no observable change.

Since the salt content in meat gives rise to an electrolyte, one would expect an observable deflection.

Aluminum foil will produce an effect similar to that of the spoon when touched to a tooth filling.

of the same kind of metal?

What would happen if you were to replace the citrus fruit with a piece of raw meat? What might happen if you touch a metal spoon to one of your tooth fillings?

You might be interested in the experiments done by the Italian physiologist and physicist, Luigi Galvani. Use your library.

D.6 - Demonstration: THE STORAGE BATTERY

Materials and Equipment

2 #6 dry cells
150 ml 0.1 molar sulfuric acid
2 lead strips about 3 x 20 x 100 mm
wires
flashlight bulb

In the preceding experiment you observed that electrical energy may result from chemical interactions. This conversion of chemical to electrical energy is very useful. Every time you use a flashlight or other battery-operated device, you are making use of just such energy conversions. Batteries are really energy converters.

The following demonstration will serve to illustrate the process involved in charging and discharging the lead-acid battery.

Place two clean lead strips (approximately 3 x 20 x 100 mm) into about 150 ml of dilute sulfuric acid (about 0.1 molar). Connect the two lead plates to the terminals of two #6 dry cells as shown in Figure D.5 and observe the changes at both lead plates. After the process has continued for several minutes, try lighting a flashlight bulb with the charged cell by removing the wires from the dry cells and connecting them to the flashlight bulb.

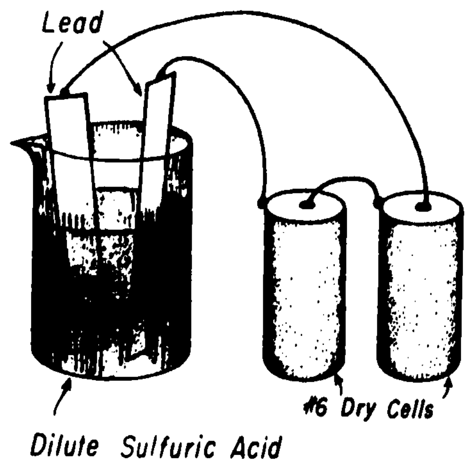


Figure D.5

The automobile battery is an interesting energy converter. During the charging process, electrical energy produced by the generator causes an increase in chemical energy of the battery. On discharge, the battery loses chemical energy as it furnishes electricity.

This may be illustrated as follows:

$$\text{Chemical Energy} \underset{\text{charging}}{\overset{\text{discharge}}{\rightleftarrows}} \text{Electrical Energy}$$

It is important to point out that the energy is stored primarily as chemical energy rather than as an accumulation of electrical charges. You will learn more about such chemical and electrical conversions later in this course.

D.7 - ELECTRICITY, LIGHT, AND LIFE

Life itself--at least in the higher organisms--depends in part on electric impulses that arise from chemical energy. Our own neural and muscular systems utilize these conversions.

See Harry Grundfest, "Electric Fishes," Scientific American, (October, 1960).

The Amazon electric "eel" is not an eel; it is related to the catfish.

In some animals, such as the electric ray (Torpedo nobiliana) and the electric "eel" of the Amazon, considerable energy may be produced. The North Atlantic electric ray can deliver as much as 50 amperes at 50 to 60 volts. We might point out that most fuses in your home would be blown out by a current more than 20 amperes. An African catfish is able to produce a 350-volt shock, while the Amazon electric "eel" can generate enough electricity to light several household light bulbs. It can, in fact, deliver a jolting 500 volts. As you can well imagine, the current generated by such voltages may kill a man.

The organ which produces electricity within an electric fish may account for about 80% of the fish's bulk. It is made up of columns of tiny structures called electroplaques. There may be more than fifty such columns each consisting of about ten thousand electroplaques. Nervous stimulation of the electroplaques causes chemical energy to be converted to electricity.

Strange as it may seem, plants, too, are capable of producing electricity. The growing root of a bean shoot has been found to act as an electric generator producing very feeble electric currents. Even the microorganisms get into the act. Scientists have recently been experimenting with fuel cells in which bacteria produced the electricity. All of these organisms are energy converters in which biochemical changes produce electric energy.

The candle, kerosene lamp, and gas lantern are also converters of chemical energy. These converters are primarily used as sources of light although most of the chemical energy is converted to heat. To be highly efficient as a light producer, the chemical energy should be converted to a "cold light." A chemical interaction in which the bulk of released

It might be possible to demonstrate chemiluminescence if you can obtain some *"luminol" (an Eastman organic chemical). In the radioactivity chapter the student will encounter phosphorescent substances.*

energy is converted to light and not heat is called chemiluminescence.

On a warm summer night youngsters in the Midwest often amuse themselves by catching "lightning bugs" or fireflies. These fascinating insects are found flying leisurely above the lawns, producing green flashes of light. The light produced in the insects' abdomen is a "cold light" resulting from chemical interactions. The biologist calls this process bioluminescence. There are many more examples of bioluminescence in a variety of other organisms. Again we see an example of energy conversion:

$$\text{Chemical Energy} \underset{\text{photosynthesis}}{\overset{\text{bioluminescence}}{\rightleftarrows}} \text{Light Energy}$$

There are many unanswered questions concerning life processes. Since all life depends upon energy conversions some of the answers to these questions will come from a better understanding of energy conversions in biological systems.

E. - CONSERVATION OF ENERGY: THE FIRST LAW OF THERMODYNAMICS

In this chapter you have become acquainted with many forms of energy: electrical, mechanical, chemical, and of course, heat energy.

What allows us to call all of these phenomena by the same name, energy? It is just this: When any amount of one kind of energy disappears, other kinds appear. And what is even more important, when expressed in the same units, careful measurements show that the total amount that appears exactly equals the amount that disappears.

Richard Feynman, the colorful Nobel-prize-winning physicist, has compared this aspect of nature to the antics of a spirited youngster he calls "Dennis the Menace," who persists in teasing his mother by hiding his toys. Dennis owns 28 blocks, and his mother usually counts them every day. One day there are only 26 blocks to be seen, but she notices the toy box is locked. Happening to know the normal weight of the toy box, she weighs it again and finds that it is heavier. The difference in the weight divided by the weight of a single block yields the number 2! Thus she can account for the two missing blocks; they are in the toy box. The missing items are thus manifested as a weight, but using a conversion factor (the weight of one block) this weight can be expressed as a number of blocks. Feynman goes on to recount further variations in this game between Dennis and his mother. For instance,

Feynman, Leighton, Sands, "The Feynman Lectures on Physics" Volume I, p.4 - 1 (Addison-Wesley, Reading, Mass. 1963).

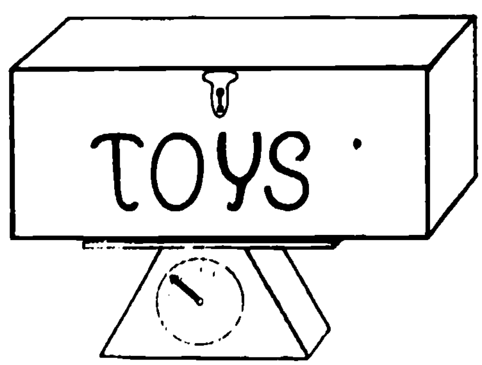


Figure E.1

when some blocks are hidden in a sink of dirty water, his mother can determine that the total number of blocks is still the same by measuring the increase in water level.

This story is far-fetched, but the analogy is clear. The blocks represent energy, Dennis is devious nature, and his mother is a curious scientist. No matter how elaborate a scheme Dennis thinks up to hide the blocks, his mother, by being clever enough, is able to show that the total never changes. Blocks are conserved! So it is with energy. No matter what form nature chooses to display energy in, scientists are always able to show that none of it actually disappears. Energy is conserved.

This principle was not always known to be true. Part of the reason is that it is often difficult to measure carefully all the energies involved in some experiment without letting some escape undetected. Therefore our present knowledge of energy conservation is a result of many experiments coupled with a search for regularities. It was not until the mid-19th century that it became clear that conservation of energy was apparently true and its significance understood. In the developing science of thermodynamics (thermo = heat, dynamic = power, strength) it is called the First Law of Thermodynamics. Scientists have great faith in this idea. Whenever it has seemed to be threatened, rather than abandoning the principle scientists have preferred to look for some new form of energy to account for some missing amounts. So far this approach has never failed.

Exercises for Home, Desk and Lab (HDL)

(1) a. What heat or temperature changes are noticed in a roomful of people when doors are closed? Explain.

(1) a. There is a rise in temperature because bodies radiate heat.

b. Arrange a series of household tasks or activities in order of decreasing energy requirements.

b. Possibilities: scrubbing floor (by hand), sweeping, washing windows, making beds, dusting, carrying out garbage, washing dishes.

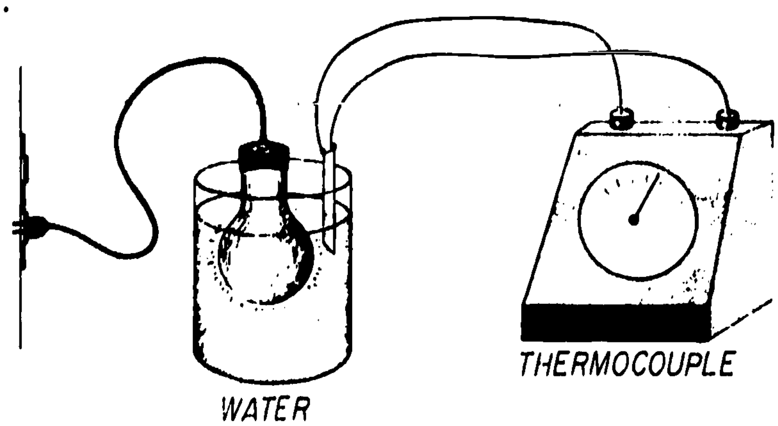
(2) Why does a nail become hot when it is hammered vigorously?

(2) The kinetic energy of the hammer increases the random translational motion of the molecules in the nail. The increased kinetic energy of the molecules shows up as a rise in temperature.

(3) Use the "⟶" to indicate the energy conversions occurring in the following situation.

(3) electricity ⟶ heat ⟶ electricity or electricity ⟶ heat ⟶ electricity

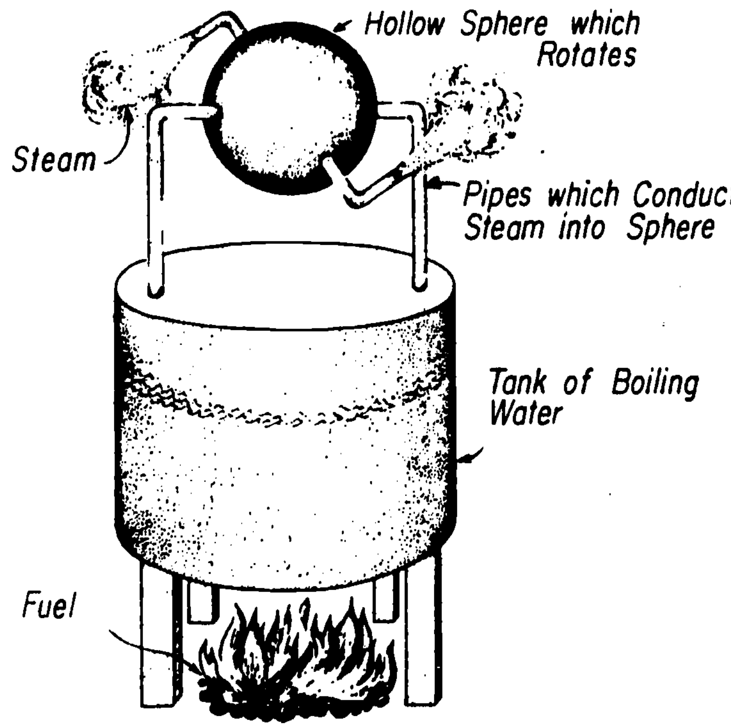
electricity ⟶ light



(4) chemical heat energy
energy ⟶ of water ⟶
(fuel)

kinetic
energy energy
of ⟶ of
molecules rotation
(steam)

(4) Use the "⟶" to indicate the energy conversions occurring in the apparatus diagrammed below.



(5) This apparatus should be put on display during the study of Chapter III. The radiometer can be purchased from OMSI, Welch, etc. If students ask to see it, handle it, experiment with it, they should be encouraged. However, the teacher should not develop the theory or history of the radiometer at this time. The teacher may want to preview the PSSC film "Light Pressure." By having the display, the teacher will help set the stage for later materials.

The most likely student answer will be:

light ⟶ KE (rotation)

but why not

heat ⟶ KE?

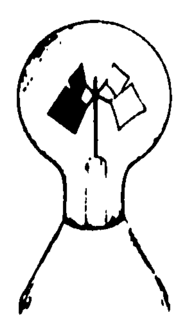
or both:

light and heat ⟶ KE

or even

radiant energy ⟶ KE

(5) You have seen the eye-catching device pictured below. It is often seen in shop windows--put there to get you to stop. It spins with no apparent source of energy. What energy conversion is involved? Speculate on what makes it operate.



(6) The sun is the ultimate source of the energy man uses during his life. Trace the energy of rotation (kinetic energy) of the Bonneville Dam generators back to the sun. Use "$\longrightarrow$". Do likewise with the energy in the sugar of a candy bar.

(7) Suppose that in the demonstration in Sec. B. 2. we had found a 4-minute trial with a 100 watt bulb would raise the temperature of 800 ml of water 4.0° C. How many calories were produced? Use this result to fill in the table of predictions.

Bulb Size (watts)	Water Volume (ml)	Time (min)	Heat Produced (cals)	Temp Change (° C)
200	800	4		
100	1600	4		
1000	400	1/2		
100	800			1.0° C

Time (min)	*Heat Produced (cals)*	*Temp Change (° C)*
4	*6400*	*8.0*
4	*3200*	*2.0*
½	*4000*	*10.0*
1	*800*	*1.0*

(8) a. In the demonstration of Sec. B.2 does 100% of the electrical energy go into raising the water temperature?

(8) a. Trial data indicates less than 60% of the energy raises the water temperature.

"Leaks"

b. *(1) Evaporation of water occurred near the hot bulb and at the surface. The loss is 540 cal/g but even so it should be small. "Plug it up" by putting a lid on the surface.*

(2) Light passed through the water and escaped. How about surrounding the jar with opaque material?

(3) Heat may have passed through the water and escaped. Place opaque material or layer of metal foil around the jar to reflect the heat back.

(4) Heat was lost through the socket. No easy remedy.

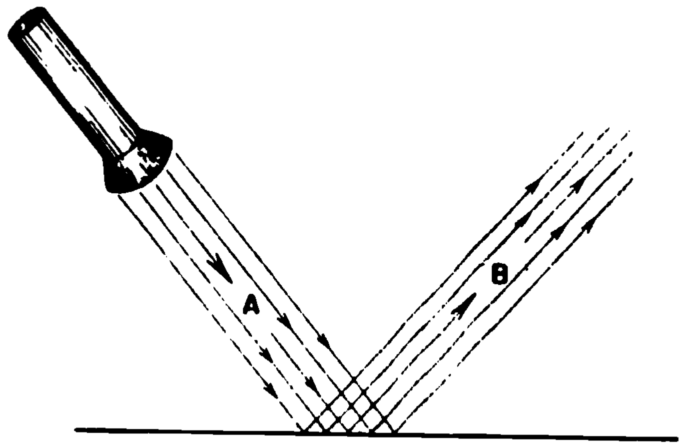
(5) Heat was used in raising the beaker's temperature. Find a way to calculate how much went this way.

b. Can you think of at least four energy "leaks"?

c. How would you go about "plugging up" these leaks?

(9) Since energy is conserved, all of it must be accounted for. A large part of it was involved in the work of bending metal. Some of the bent metal parts are like springs in that they contain stored energy. Many of the parts are hot; part of the heat energy from the collision has activated the molecules. The shock and sound waves (movements of molecules) removed some of the kinetic energy. There are other conversions involved, but those mentioned above would be sufficient.

(9) Two automobiles approach at 40 mph and collide head-on. Before the collision each contained kinetic energy. They do not bounce apart but remain a stationary wreck. There is no appreciable skidding. What happened to the kinetic energy?



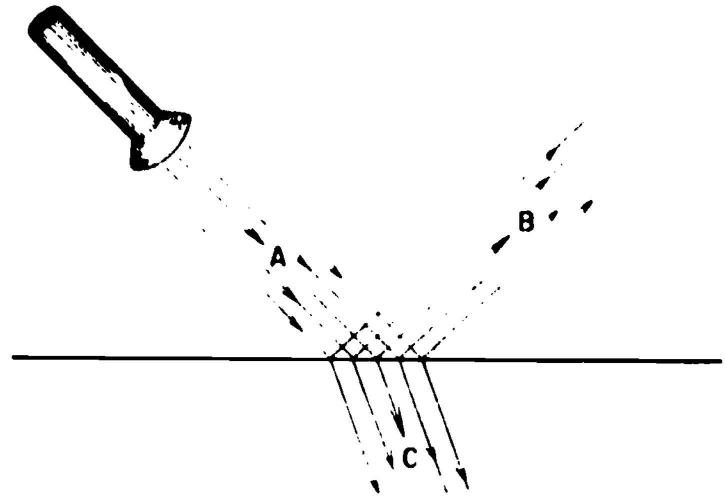
(10) a. A flashlight is shone upon a mirror, bouncing its beam upward. A photographer's light meter is used at A to measure the light approaching the mirror and at B to measure the amount of light leaving the mirror. Experimentally, B is smaller than A. Speculate on what happened to the missing light.

(10) a. A part of the light energy is absorbed at the surface. The surface temperature is raised as a result.

Light ⟶ Heat

A large amount of light converts to a small amount of heat energy. The surface temperature change is usually missed.

Students may suggest other explanations. They may suggest that it is reflected off the mirror in other directions. The question's purpose is to get them to speculate.



b. The missing light is absorbed, primarily at the surface of the water.

b. A similar arrangement is made with the light shining on a smooth water surface. If 100 units of light pass A, experimental results show something like 40 units arriving at B and 40 units arriving at C. Some of the light has reflected, but some has entered the water. Speculate on what may have happened to the missing 20 units of light.

(11) Most of the fuel cells in use today (military and space vehicle applications) consume hydrogen and oxygen. The only product in this case is water. This would not cause air pollution since it is pure water.

The student may find that other fuel cells use hydrocarbon fuels and air. In that case the products of combustion might be water and carbon dioxide. Pollution would

(11) The fuel cell is an energy converter which is being used in some specialized industries What substances are consumed by the fuel cell in the generation of electricity? What are the waste products from the cell? How will these products affect air pollution as more cells come into general use? (Use your library.)

not be a problem unless the "combustion" process is incomplete. Fuel cells in general would be less likely to cause air pollution than our present combustion engines.

This item should stimulate discussions concerning the future of electric autos, independent power sources for homes and power sources for space vehicles.

(12) The bunsen burner is an energy converter.

a. What substances are consumed by the burner?

b. What are the main products of combustion?

c. Show the energy conversions schematically.

(12) a. The burner uses a hydrocarbon fuel (methane) and oxygen of air.

b. The products of combustion are water and carbon dioxide (assuming complete combustion).

c.
Chemical Energy $\longrightarrow$ Heat + visible light

(13) Engines can be built which will run on a mixture of hydrogen and oxygen instead of on gasoline and air. This same engine can be used to drive a generator which will produce electricity. The electricity can decompose water into hydrogen and oxygen.

a. Show the energy conversions involved in this operation.

b. Would this system continue to operate on its hydrogen and oxygen output if it were fed into the gas engine?

(13) a. Chemical Energy $\longrightarrow$

Mechanical Energy $\longrightarrow$ Electrical Energy $\longrightarrow$

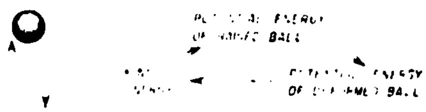
Chemical Energy

b. The amount of hydrogen and oxygen produced by the electrolysis of water in this system is less than the amount used by the engine; therefore the system runs down. Energy losses in the system prevent such perpetual motion.

(14) The thermopile is a series of thermocouples used for the generation of thermoelectric currents. It is also used in instruments for the detection and measurement of heat (radiation thermopile).

(14) What is a thermopile?

(15) An earth satellite speeds up when it is closer to the earth and slows down when it is higher. A bouncing ball involves this cycle.

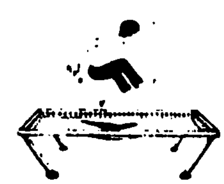


Nature offers many other examples.

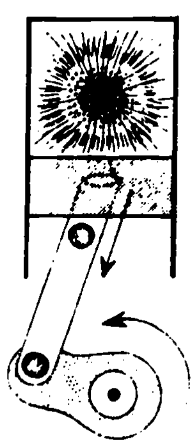
(15) Can you think of cyclical conversions of potential to kinetic energy similar to those of a pendulum?

(16) Same as the ball in problem 15, except the PE of deformed ball is replaced by PE of stretched springs. Heat losses in springs are made up by energy input from boy.

(16) What are the energy conversions of a boy bouncing on a trampoline?



(17)



(17) Find out how a gasoline or reciprocating steam engine works. Can you name some of the energy conversions involved?

Chemical energy of burning fuel
↓
Heat energy of cylinder gases
↓
Kinetic energy of moving pistons
↓
Kinetic energy of rotating crank-shaft

The potential energy of the rising and falling piston alternately takes and gives energy to the flywheel.

(18) a. What effect does sweating have on the body?

b. How many calories are required to vaporize one gram of perspiration (water)?

(18) a. Sweating cools the body.

b. 540 calories are required to vaporize one gram of water.

(19) Explain the cooling effect of alcohol.

(19) Alcohol evaporates rapidly and requires heat to change phase.

(20) Will ice at 0°C cool a glass of tea as much as the same amount of water at 0°C?

(20) Ice at 0° contains less heat than water at 0°C.

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
A. Becquerel and his mysterious rays	1 Day			Film: "Atomic Research: Areas and Development" Cornet Film, 13 1/2 min., B/w. Excellent introduction to chapter.			
		A.1 Reproduce Becquerel					
A.2 Radioactivity	1 Day	A.2a Detecting radioactivity by scintillation counters					
		A.2b Shielding from radiation					
	1 Day	A.2.c Count per minute from various sources					
			A.2.d Cloud chamber				

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
A.3 - Nature of radiations	↑			Film: "Radio-activity" McGraw-Hill Book Company			
A.4 - Radiation and you	3 Days						
A.5 - Radio-activity in the natural environment							
B - The source of the energy							
B.1 - Nuclear energy	↓	B.2 - Counting Rate					

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
B.3 - Comparison to chemical energy							
B.4 - Half life							
B.5 - Nuclear transformation	1 Day						
C. - Man and nuclear energy							
C.1 - Control of rate of energy release							
C.2 - Harnessing the nucleus				Film: "Our Friend the Atom" (2 parts) Disney 48 minutes. Use as a summary.			
C.3 - Fusion							

Chapter IV: NUCLEAR ENERGY AND RADIOACTIVITY

A. - BECQUEREL AND HIS MYSTERIOUS RAYS - AN UNEXPECTED SOURCE OF ENERGY

We have seen manifestations of energy in its many forms and its transformation from one form to another. We concluded that energy in one form did not simply appear; it always arose from some other form. In 1896 the French physicist Becquerel found a substance that apparently gave off small amounts of radiant energy in undiminished quantity for long periods of time. These radiations were similar in some respects to the x rays which the dentist uses to photograph your teeth. They were capable of penetrating normally opaque materials but could not be explained on the basis of any known energy transformation--chemical or otherwise.

This history is reviewed in Harvard Project Physics, Unit 6; also see Chapter 7, <u>Introductory Physical Science</u>.

Do you know what transformation is involved in producing your dentist's x rays?

High speed electrons are made to converge on a metal target, which emits the rays. Hence the conversion is:

Electrical energy $\longrightarrow$ *Radiant energy*

Use a Land Filmpack, Type 107. All the film sheets will be exposed at one time. The samples are those used in Introductory Physical Science 7.1. The IPS experiment uses single film sheets, but the filmpack may be easier to obtain and, in addition, will show partial absorption from one sheet to the next.

The samples supplied in the IPS materials are as follows:

Sample	*Substance*	*Radio-active*
A	*Uranium sulfate*	*Yes*
B	*Sodium sulfate*	*No*
C	*Uranium nitrate*	*Yes*
D	*Sodium nitrate*	*No*
E	*Thorium nitrate*	*Yes*
F	*Sulfur*	*No*

A piece of film wrapped in paper is placed behind the teeth. X rays are beamed in from the front.

A.1 - Experiment: ENERGY CHANGES AFFECT FILM

We will try to reproduce some of the observations of Becquerel. When a photographic plate is exposed to light, a chemical transformation takes place which results in the production of an image during the process known as "development." Light energy is transformed to chemical energy. The development process involves a further series of chemical changes which reveal (by changes in lightness and darkness) which regions of the photographic film had been exposed to the light and thus underwent the original energizing process. Even radiant energy which cannot normally be detected by the eye will produce this phenomenon of darkening a photographic plate. (Can you recall what procedure the dental assistant used the last time she photographed your teeth?)

We will use Polaroid film which can be developed in the classroom. Your teacher will supply several samples of materials contained in identical plastic boxes which you can place on the opaque safety cover of the film pack. Be careful to mark the place on the cover where each sample was placed. Leave this arrangement undisturbed for 3-5 days, and then develop all the film in the pack. Can you decide what substances or components of a substance are responsible for the results you observe? Is there a difference from one film to the next? Be sure to keep track of the order in which the films were stacked in the pack.

A.2. - SOURCE OF RADIOACTIVITY

Materials which give off penetrating rays of the sort observed here are called radioactive. No ordinary chemical transformations seem to be involved. All chemical combinations of the same basic substance, such as uranium, show the radioactive effect. What is even more surprising, if any of the uranium is "used up" in the process, the amount is very small. Becquerel found that the ability of his materials to give off this radiation was undiminished in three years. We shall see that actually something is "used up" and that the radioactivity diminishes slowly with time. However, it was clear to Becquerel that no ordinary chemical process was involved. This was evident from the fact that the strength of the radiation did not depend on the various chemical combinations that could be made with the radioactive substance (such as uranium). The emanations had to do strictly with the uranium itself. It eventually became clear that the source of the energy is in the very heart of the atom, i.e., its nucleus, and hence is called nuclear energy. The outer part of the atom, which is involved in ordinary chemical processes such as burning, is not involved.

Materials and Equipment
- *small cardboard box with cover*
- *magnifying lens*
- *zinc sulfide, phosphorescent grade (yellow, not white)*
- *radioactive source (polonium 210)*

A.3. - Experiment: NUCLEAR ENERGY CONVERTED TO LIGHT

We will build a simple device for detecting the radioactive emanations more directly than in the photographic process. When certain energetic rays fall upon a luminescent substance, some of the energy is converted directly to light. This process is known as scintillation, and instruments which use this principle to detect and measure radioactivity are called scintillation counters. The simple model we will make is sketched below.

A box no more than about 2 ½ inches in depth should be used. The magnifying lens should be such that an enlarged view of the bottom of the box can be seen. The shorter the box, i.e., the shorter the focal length of the lens used, the greater will be the magnification and the easier it will be to see the effect. Make sure the lens is pointing directly at the small hole.

Do not embed the phosphorescent material in a binder that will not evaporate (and thus absorb particles). One method for coating the surface is to first spread a coating of rubber cement and sprinkle on the powder. Rough cardboard might hold enough without any special coating. A slurry with xylene might also be tried.

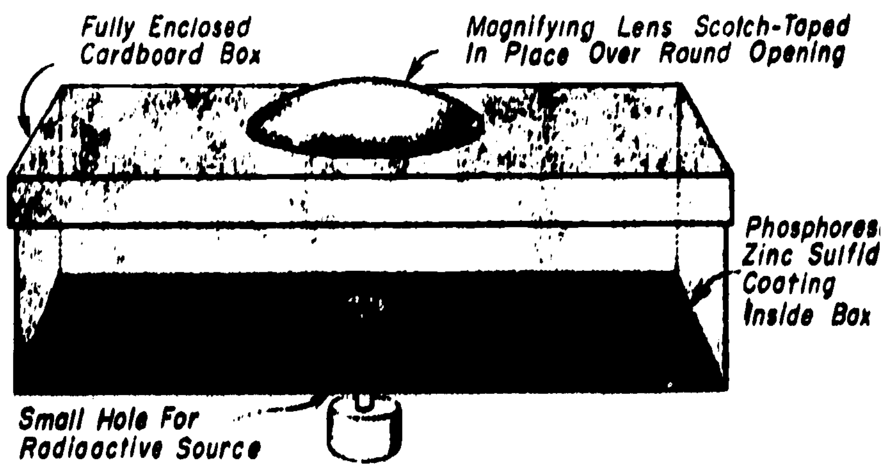


Figure A.1

Adjust the height of the box lid so that the lens gives a clear magnified view of the little hole in the bottom of the box; then pin or tape the lid to hold it at this distance. The luminescent material used may also give off a steady glow for some time after being exposed to ordinary light. This phenomenon, known as phosphorescence, represents chemical energy slowly being converted to light. After about 10 minutes in the dark, the glow should be weak enough not to interfere with observation of the scintillations. The radioactive source supplied by your teacher is a type known as an alpha-emitter, usually a small bit of polonium metal deposited on the end of a pin or wire.

To observe the scintillations, two precautions must be taken. (a) Remain continuously in a dark room for 10-15 minutes and then observe in the dark. This will permit the eyes to become "dark adapted" so that small amounts of light can be seen. (b) Arrange the source so that it doesn't protrude more than about 3 mm above the luminescent surface. Some of the radiation which is important in this process is intercepted appreciably by air.

Insert and withdraw the source from the hole several times during your observations. Make sure the effect you see is correlated with the presence of the source. Do you see any

Light-emitting chemicals are described by several terms. Luminescence is a general term which includes fluorescence (light is given off only when stimulated) and phosphorescence (light is gradually given off over a period of time after stimulation). When buying zinc sulfide make sure it is "phosphorescent grade" (a yellow powder). Ordinary white zinc sulfide doesn't work. (OMSI or Fischer Chemical sell small bottles.) Type P7 phosphor (used for coating oscilloscope tubes) also works nicely. This might be obtained from Tektronix.

Make sure the source is fresh. If it is essentially Po210 it has a half-life of 138 days. Welch, OMSI, and IPS suppliers sell these sources. They can also be used in the cloud chamber.

changes when the source is moved higher or lower with respect to the bottom of the box? Look up the definition and derivation of "scintillate" in the dictionary. Is the device aptly named? Do you think it is small particles or light-like radiation which is responsible for your observations?

A.4.-SOME OF THE PROPERTIES OF THE RAYS

A.4.a. Experiment: PENETRATING POWER

Materials and Equipment

same as those for A.1
plus thin plastic
pennies
lead slug
aluminum foil
you name it

You might have noticed in experiment A.1. that there was a variation in intensity of the radiation from one film to the next. Apparently film is not perfectly transparent to nuclear radiations. Test some other materials for their ability to shield the film from the rays by placing thin samples of them between various radioactive sources and the film pack. In particular try a thin sheet of some very heavy metal, such as lead. You might also try to see whether the penetration of the rays depends on the thickness of the shielding material.

A.5. - MORE PROPERTIES OF THE RAYS -- PARTICLE-LIKE BEHAVIOR

A.5.a. - Experiment: THE GEIGER COUNTER

Materials and Equipment

Geiger counter
samples from A.1

Place each of the various substances used in the photographic film experiment near a Geiger counter. Is there a correlation between the substances which most affect the film and those which most affect the number of clicks registered in a given time? (The intensity of the radiation is often stated in terms of counts per minute, CPM. The scale on your Geiger counter may be calibrated directly in terms of CPM.) It is as if little invisible particles were flying off from the radioactive source causing a click whenever one entered the counter. Is there any way of predicting precisely when a click will be heard? Do you think you can predict how many clicks will be heard on the average in a given interval of time?

More quantitative work with the Geiger counter comes later on in this chapter.

A.5.b. - Demonstration: THE CLOUD CHAMBER

This is another important device which lends support to the idea of radioactive materials giving off particle-like emanations. Each vapor trail marks the path of some passing nuclear ray. Note that occasionally you may observe a trail which did not seem to originate from your radioactive source but from somewhere outside the cloud chamber. You may be able to explain this phenomenon after reading paragraph A.8.

Materials and Equipment

Use the IPS dry ice and alcohol cloud chamber. The chamber is a plastic box which comes with a polonium source placed on a needle mounted in the box. Inside the top of the chamber is a felt band to be soaked with methanol or isopropyl alcohol. About an eyedropperful should be adequate.

The entire chamber then is to be placed on a block of dry ice. This is usually available from the dairy which supplies the school kitchen.

After 5 to 10 minutes on the ice block the cloud chamber should be cold enough to supersaturate the alcohol vapor, allowing fog tracks to form. They will be more readily visible against the black bottom if the chamber is lighted as with a flashlight.

A.6. - THE NATURE OF THE RADIATIONS

In general, radioactive materials give off both particles and light-like emanations. The

The chamber should show tracks for about 20 minutes if the CO_2 block is mounted on a styrofoam slab or other suitable insulation.

The Po^{210} source gives off α and γ rays. The rays are detected by the scintillator. The cloud chamber "sees" α and β rays. The Geiger counter detects β and γ rays.

particles are electrons (tiny, negatively charged bits of matter which form the outer parts of atoms) and alpha particles (much heavier positively charged bits of matter which form the central core of helium atoms*). These are symbolized by the letters e^- and α respectively. The x ray-like emanations, called gamma rays (symbolized by the letter γ), are emitted in a short burst each time an atom undergoes a radioactive transformation. Hence, even γ rays have a particle-like aspect in that they affect our detectors for a short instant as the burst passes by. The amount of energy carried by each of the various emanations (usually called collectively "rays" or "nuclear radiation") and the relative abundance of the various types of rays depends upon the particular radioactive material. Some of these radiations, such as γ rays, are extremely penetrating. Others, such as α rays, may be stopped by relatively small amounts of material. For instance, the α rays given off by many luminous watch dials (which are painted with a

*Helium is the non-flammable gas which is used to fill the lighter than air balloons you have seen at the zoo or at parades, and which has many important industrial applications as well.

mixture of luminescent substances such as ZnS and a trace of a radioactive material) are stopped completely by the glass cover on the watch. β rays can penetrate the glass and will be detected by your Geiger counter if they are given off by the watch. How much air was sufficient to block off the rays given off by the Po source in the scintillator experiment?

A.7. - RADIATION AND YOU

Why does your dentist (or his assistant) go into another room each time he takes an x ray "snapshot" of your teeth? Although there are many ways in which the phenomenon of radioactivity can be put to useful service by man, he must use it with the utmost care. Nuclear radiation can alter chemical combinations in the body and thus interfere with its proper functioning. (We can think of this in terms of the following analogy: If a stray bullet severs some cables in a suspension bridge, it may collapse. Likewise, γ rays can destroy chemical links between atoms and change the chemical processes in the body cells.) In earlier days much harm was done by radiation due to ignorance of the phenomenon. Women who painted luminescent watch dials in

This is to protect against cumulative doses of radiation.

The radioactive chemical salts in the paint can become incorporated into body tissues.

France early in this century often died of radiation poisoning. They had the habit of wetting the tips of their brushes with their tongues. Do you think any modern worker would think of doing that, whether or not he understood radioactivity?

By international agreement a standard red and yellow symbol indicating the presence of radioactive materials has been adopted.

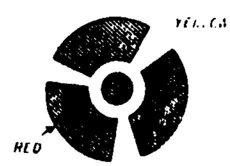


Figure A.2

Whenever you see this symbol you are being warned that a potential hazard exists. This is no cause for panic; on the contrary, it indicates that a responsible authority is aware of the situation. Before you proceed further you should seek the advice of the person in charge. He should know what the material is, how it should be handled, and what precaution might be necessary.

A.8.- RADIOACTIVITY IN THE NATURAL ENVIRONMENT

Not all radioactivity can be avoided. The occasional clicks which your Geiger counter emitted even in the absence of your test samples is evidence of so-called "background radiation." Some comes from the tiny amounts of radioactive material occurring almost everywhere, but most comes from the far reaches of outer space. We are largely protected from this "cosmic radiation" which envelops the earth by the relatively thick blanket of air in which we live. A little always leaks through and over the ages is thought to have been at least partly responsible for triggering the genetic changes which have marked the upward progress of life from its simplest types to its present diverse and complex forms. You will learn more about this subject of genetic mutation later in this course.

What precautions against radiation might you take if you were an astronaut living on the moon?

Students might recall that during the Apollo moon landing there was a solar flare warning system. If a flare occurred the astronauts were to take refuge in the space ship to protect them from radiation.

B. - THE SOURCE OF THE ENERGY

B.1. - NUC .AR ENERGY

W. have seen many examples of energy changes: electrical to heat, mechanical to heat, chemical to electrical, etc. In no case was energy created; rather energy was transformed from one form to another. What a surprise it was then for early workers to find that certain substances seemed to be an unending source of energy! One gram of radium releases about 100 calories of heat per hour--and it will continue to do this at a practically undiminished rate for hundreds of years.

To raise 10^3g H_2O from 0^oC to 100^oC requires 10^5 calories.

To deliver 10^5 calories in 1 hour, 1000 or 10^3g radium would be required.

To deliver 10^5cal in ¼ hour, 4 x 10^3g radium would be required.

Data from peanut fuel will determine the equivalent heat source.

How much radium would you have to place in one liter beaker of water to raise it from the freezing point to the boiling point in 15 minutes? Approximately how much "peanut fuel" would have to be burned in order to produce the same amount of heat?

This is an astounding phenomenon in comparison with the usual energy conversions you have studied. The energy does not in fact come from any of the sources you have already examined. It comes from the material constituting the very heart of the atom, i.e., from the nucleus.

Materials and Equipment
Geiger counter
samples from A.1

B.2. - Experiment: COUNTING RATE

Our object is to see if we can tell any change in radioactivity over a short period of time. We will use the Geiger counter to detect the radioactivity. We must, however, make a correction in our data for the ever-present background radiation.

Besides determining the correction, counting background is good practice in using the apparatus before the main part of the experiment. Occasionally several counts come almost at once (in a "burst"). Students can usually estimate the number as 2 or 3. A small error is not important.

Using the IPS source "A" at about 8 inches from a civil defense type Geiger counter gives about 60 CPM.

Making sure that the Geiger tube is not near any of our radioactive materials, determine the number of clicks (or "counts") due to background radiation in a 10-second interval. Do this 10 times in order to get a good average number for the counts observed in each time interval. Now place your counter tube near one of the radioactive samples used in the photographic film experiment. If you position the tube so that you get roughly one count per second you ought to be able to obtain the required data. Determine the number of counts in a 10-second interval, repeating for 60 to 100 intervals. Record the number of counts minus the average number of background counts in each interval. Also record the time at which the interval began. Plot the number of counts per interval versus the time elapsed from the start of the experiment, then draw an average line through the points. Can you tell from these data whether the radioactivity of your sample material has changed significantly?

Further reading in the teacher guide to the Harvard Project experiment 44 might be useful.

To answer this question, you must think somewhat carefully about the meaning of the word "significant." You have undoubtedly noticed that the production of a click in the Geiger counter constitutes a random event, an idea you have already encountered in the Perception and Quantification unit. It is not possible to tell at any given instant whether

A thorough discussion of statistics is not intended. The idea is that a limited number of random events imply limitations on the data. Within the limits of error the radioactivity is undiminished, i.e., it doesn't change more than a "significant variation" during the experiment.

a ray will be emitted and detected. The important quantity to be noted is the average number over a period of time. You may find it revealing to plot a histogram of your data giving the number of intervals in which a given number of counts was observed. The peak of the distribution represents the most probable value for the counting rate, but variations from interval to interval occur. We may assume that a significant variation is a departure from the peak value roughly greater than that which occurs halfway down on the distribution curve. This is illustrated in the following graph.

If we used many and longer intervals, a relatively smooth curve would be obtained.

The significant variation would be relatively smaller.

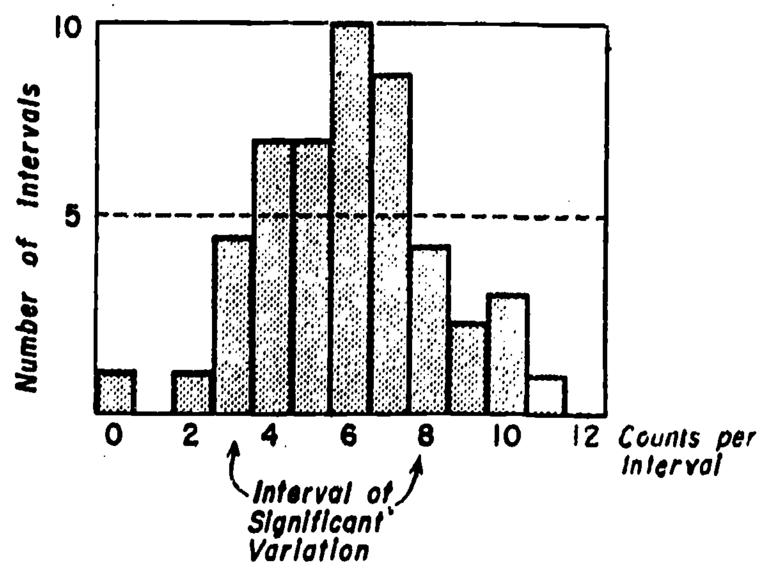


Figure 8.1

In this example, the most probable value is about six counts per interval. A significant variation from this value is about two counts. In your graph of counts versus time, is there a steady increase or decrease which is greater than a significant variation?

B.3. - COMPARISON TO CHEMICAL ENERGY

We have seen that some types of energy result from the way in which atoms are put together to form bigger chunks of matter. For instance when gases condense to form liquids (such as when steam becomes water) energy must be given off, because as the atoms come closer together the potential energy associated with forces between them decreases. Likewise, when peanuts are burned there is a so-called "chemical change"--the atoms in the fuel are rearranged and combined with oxygen in such a way that the final products (can you name them?) are less energetic than the original ones. In the process, heat and light are given off.

See HP Physics, Unit 6, page 81.

water, carbon dioxide, etc.

Likewise there can be a rearrangement in the structure of the nucleus itself. Radioactive substances are materials whose nuclei will occasionally change to a lower energy situation--that is, the particles forming the nucl us will take on a new arrangement. In the process some parts of the nucleus will be expelled. These form α and β particles, which carry kinetic energy away from the nucleus. Likewise, radiant energy will be given off in the form of γ rays. What will be left is a transformed nucleus, a

Very crudely the α and β rays may be likened to smoke, the γ rays to light and radiant heat, and the daughter nuclei to the ash.

so-called "daughter" nucleus.

In a chemical reaction like burning, what corresponds to the α and β rays, the γ rays, and the daughter nuclei?

As with chemical reactions we may have both exothermic and endothermic nuclear reactions. The cases you have been observing are exothermic; during the rearrangement of nuclear particles, energy is released. In some cases, such as processes examined by physicists using large research machines such as cyclotrons, energy has to be added to produce a transformation. For instance, one nucleus can be "shot" at another nucleus so that they fuse together. Most often these are endothermic processes.

$p + U^{238} \longrightarrow P^{239}$ is an Endothermic reaction

Principal of "breeder reactor." P^{239} is produced from U^{238} which is used as fuel.

B.4. - HALF-LIFE

If the nuclear rearrangement process resembles a chemical rearrangement, why is it that often no decrease in the amount of radioactivity is observed over a period of time? Aren't the nuclei "used up" in the process of being transformed to daughter nuclei? In other words isn't the fuel of the "nuclear combustion" eventually consumed? The answer is actually "yes," but in the cases we have studied, the rate at which the "fuel" is used up is very small indeed, even though relatively

See HP Physics, section 24.10.

large amounts of energy are released. For each nucleus that undergoes a rearrangement, there is involved a relatively large amount of energy. In fact, each nuclear event involves about a million times more energy than is involved in the chemical reaction of a single atom. It doesn't take many radioactive events per minute to release a sizeable amount of energy. Thus the radioactive material is indeed gradually used up, but in the substances you have been experimenting with, the rate is too slow for us to measure easily.

There is no way of predicting the precise moment at which a nucleus in a radioactive substance will undergo a transformation. It is, as you have seen, a random event. However, there are so many nuclei in any class size sample of the material that we can be quite sure that a predictable number of them will, on the average, transform in a given period of time. We may denote the relative rate at which the material is used up in terms of "half-life," which is defined as follows: starting with a given amount of radioactive material, the time it takes for it to be half used up is called the half-life. Some values are as follows:

Substance*	Half-life (T 1/2)
Uranium 238	4.5×10^9 years
Thorium 230	8.0×10^4 years
Radium 226	1620 years
Lead 210	21 years
Polonium 210	138 days

As the amount of a radioactive substance diminishes, the strength of the radioactivity diminishes in proportion. Roughly how long would you have to wait before your polonium source became 1/4 as strong as it is at present? How long before it became 1/8 as strong? Can you devise an experiment to check your prediction?

276 days; 414 days, roughly a year.

B.5. - NUCLEAR TRANSFORMATION

After a nucleus undergoes a rearrangement of its constituent particles (thereby emitting energetic fragments we have called α and β particles), what is left? The "daughter" nucleus is obviously different from the "parent" nucleus. This has an effect on the electrons surrounding the nucleus to form the atom. In fact a radioactive event transforms the atom into a different kind of atom, one with

* The numbers following the name of the substance is a common way for scientists to designate certain materials: It represents the total number of major particles in the nucleus.

different physical and chemical properties. One particular case is diagrammed below:

$$\underset{\text{(a radioactive metal)}}{\text{Radium 226}} \xrightarrow{T\ 1/2\ =\ 1620\ \text{years}} \underset{\text{(a radioactive gas)}}{\text{Radon 222}}$$

But this, it turns out in this case, is not the entire story; each radon atom eventually transforms into a form of polonium; the polonium in turn transforms; and so forth, until a non-transforming (non-radioactive) atom is formed. In this particular series of transformations the end product is the non-radioactive substance lead 206.

C. - MAN AND NUCLEAR ENERGY

Can man control the rate at which the release of radioactive energy proceeds? What, for instance, would happen if you heated a radioactive substance? (We might even attempt this as an experiment on some of our test samples, except that we would run the risk of vaporizing some of the material, thereby spreading the radioactivity around the room.) The answer is that ordinary amounts of heat would have no affect on the rate of radioactivity.

Yes. Wood and air are perfectly stable until they are made hot enough to burn. After being ignited they continue to react unless cooled down again (with water, for instance). Most chemical situations are temperature-dependent. Some common observations: batteries, cooking, sterilizing. Nuclear energies, on the other hand, are so great per reaction that ordinary thermal motion has no effect on the situation.

Does the temperature have an effect on chemical changes with which you are familiar?

Is there some way in which we can arrest the radioactive process by combining it with other substances; can we "neutralize" the radioactivity? To this question, we must again answer "no." The ordinary processes with which we are familiar (such as chemical changes, boiling or vaporizing, electrifying, etc.) involve the outer parts of the atom, not the nucleus. Thus uranium, whether chemically combined with sulfur and oxygen to form uranium sulfate or combined with nitrogen and oxygen to form uranium nitrate, continues to be radioactive, Moreover, the strength of the radioactivity depends only on the amount of uranium present, not on the way it is chemically combined.

Most ordinary processes involve only the outer parts of atoms. It takes relatively large amounts of energy to affect the nuclei of atoms. It is only in certain special circumstances that the nuclei can be "touched." One way in which the structure of the nucleus can be influenced is by special large machines known as "accelerators" (such as cyclotrons) which are used by research physicists to study the properties of nuclei. Also in some cases, particles emitted by nuclei can influence other nuclei. And finally under extremely high temperature conditions, such as those found in the interior of the sun and stars, the structure of nuclei can be influenced.

C.1. - HARNESSING THE NUCLEUS

Ever since the 1940's, man has been increasingly involved in efforts to extract energy in large quantities from nuclear processes for useful purposes such as heating and lighting his buildings, running his factories, and purifying water. This present period, often called the "atomic age," was actually ushered in by the wartime explosion of nuclear bombs, but it is the peaceful application of this source of energy that is ultimately of greatest importance to man.

The devices which have been constructed for this purpose are known as "nuclear reactors." Large quantities of uranium are assembled in such a way that a transformation in some uranium nucleus stimulates transformations in other uranium nuclei which in turn stimulate other transformations, etc. This so-called controlled chain-reaction provides a steady release of heat, which in turn can be used to drive a

This relies on a fission reaction in which large nuclei break up into smaller ones. Fusion processes, on the other hand, build up large nuclei from smaller ones.

steam engine, and this in turn is used to produce electricity. The energy transformations in a nuclear power plant are diagrammed below:

Nuclear energy
↓ Reactor
Heat
↓ Steam engine
Mechanical kinetic energy
↓ Generator
Electrical energy

Some day the earth will run out of coal and oil. Only nuclear energy and energy directly obtained by radiation from the sun will be left to serve man.

C.2. - THE SUN, THE ULTIMATE ENERGY SOURCE

We have seen that aside from nuclear energy developed in reactors all the sources of energy used by man come from the sun. Energy captured by green plants to produce food (chemical energy), hydroelectric energy (due ultimately to the sun's influence in evaporating the oceans and producing rain), and even coal and oil (produced by living plants ages ago) are ultimately traceable to this same source. Where does the sun get its energy? If it were simply a chemical burning process, it is estimated that the sun could not continue to give light and heat more than a few thousand years. It is believed that the source of the sun's energy is in fact nuclear energy, produced by an exothermic nuclear process in which atoms of hydrogen are transformed to helium. Man may someday learn to reproduce this process, known as nuclear fusion, here on earth, where hydrogen is plentiful. This will relieve him virtually forever of the problem of finding other sources of energy whether it be from coal, oil, or even uranium.

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	OUTSIDE READING	PROBLEMS
A - Utilizing heat							
B - The second law of thermo-dynamics							1, 2, 8
C - A machine that almost worked	3 Days						3, 4, 5
D - Order and disorder		D.1 A rubber band refriger-ator					7
E - Living things and the trend towards disorder							6

Chapter V: TRENDS IN NATURE

A. - UTILIZING HEAT

We have seen in previous chapters that energy is readily convertible from one of its forms to another. Whenever careful measurements are made, however, a basic rule has always been observed to operate: no more energy can be obtained from a transformation than was put into the process from all sources. This is the first law of thermodynamics --the principle of conservation of energy. How good a job can we do in converting one form of energy to another desired form? In particular, since so much of our modern industrial world depends on producing mechanical energy (to drive automobiles, turn electrical generators, etc.) from heat energy (produced by the burning of oil, in nuclear reactors, etc.), it is particularly appropriate to ask how efficiently this sort of transformation can be made.

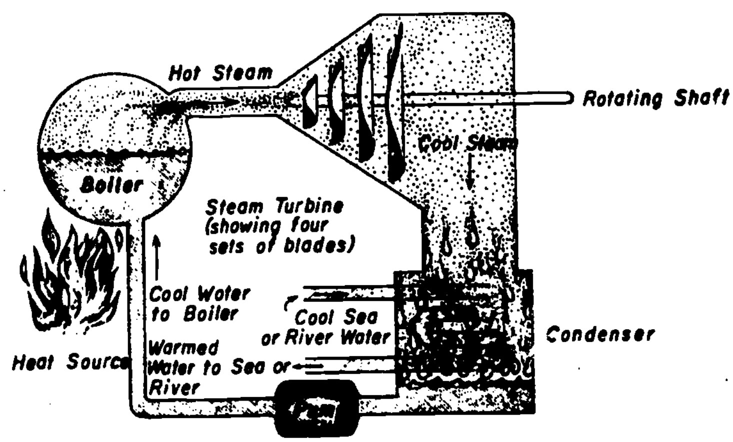
Page 92 refers to spontaneous chemical change. Here the teacher might review this, then demonstrate other spontaneous (energy-releasing) changes. What is the direction of all spontaneous change?

A.1. - A HEAT ENGINE

Let us briefly consider the machinery which is widely used in ships and power plants to generate mechanical energy. The central device, called a steam turbine, is a sort of

There has been a great deal of interest recently in the development of steam engines for automobiles. As information on this begins to appear in popular magazines and newspapers it may be of *interest to keep abreast of the technicalities involved, such as the condensing systems used, advantages over internal combustion engines, and limitations of such engines.*

...lorified rotating fan which turns whenever steam is forced past its many blades. Steam is produced in a boiler which is heated by coal, oil, or a nuclear reactor. Another essential device in this sort of power system is the condenser. Its function is to cool down and thus liquify the steam after it leaves the turbine blades so that (a) the water may be returned to the boiler and reused, and (b) space may be created at the exit side of the turbine for the continuously produced volumes of steam. The steam turbine system is sketched below.



Steam Turbine Showing Four Sets of Blades

Figure A.1

In old fashioned engines, such as those used on old railroad locomotives you have seen on TV, steam was not recirculated to the boiler <u>via</u> a condenser, but was simply exhausted to the air. This is rarely done today for several reasons. The water required in modern boilers must be very, very pure and hence cannot be simply thrown away and wasted. Pure water is expensive. Secondly, as we shall soon see, the cooler we can make the exhausted steam the more mechanical energy we can produce from a given quantity of heat.

A.2. - WHERE THE HEAT GOES

There is a major thing to be noted about the steam power system described above. Although heat is taken in and converted to mechanical energy, only part of it is so converted. A portion of the heat is extracted in the condenser and thrown away, usually into some river or the ocean. This wastage of heat is unavoidable. Even if we built the most refined engines with the smoothest, frictionless moving parts, and even if we were to perfectly insulate all the hot pipes and the boiler against all incidental losses of heat by radiation or conduction, in order for mechanical energy to be produced some heat would necessarily be lost. No engine has ever been built which does not share this characteristic. In the old fashioned steam engine, heat is lost into the air via the exhausted steam.

Auto engine: Hot exhaust gases, radiation from hot surfaces, convection, and radiation from radiator (or from cooling fins on air cooled engines), frictionly produced heat in bearings, etc. Also mechanical energy goes to essential engine auxiliaries such as fuel, oil, and water pumps and this ultimately is reduced to heat.

Can you think of the ways heat is lost by the gasoline engine in an automobile? Not all the heat contained in fuel (chemical or nuclear) is available for use by man; some necessarily goes into heating the environment.

B. - THE SECOND LAW OF THERMODYNAMICS

The law of conservation of energy itself places no serious restriction on man since there is actually plenty of energy around. For instance, the water in the ocean contains fantastic amounts of energy in the form of random molecular motion. Why is it that no one extracts this energy for doing useful work? It would not be inconsistent with the law of conservation of energy to extract heat (thermal) energy from the ocean and, say, run a sawmill aboard a ship. Why, in fact, shouldn't a ship be able to get power to cruise the oceans by gulping in ocean water at the bow, extracting a net amount of thermal energy and dumping cakes of frozen seawater out the stern?

At this point some teachers like to play the Flanders and Swann selection "Thermodynamics" from the Angel record, "At the Drop of Another Hat." Unfortunately the lyrics use the term "work" which has been avoided in this material. However, it might be explained that "work" is for our purposes what we have called "mechanical energy."

Such a ship would operate in consistency with the law of conservation of energy. However, there is a second law which prohibits such a machine. It states that all machines

There are several alternative but logically equivalent statements of the Second Law of Thermodynamics:

(a) Heat cannot be completely converted to work (the ship mentioned here could not work);

which convert thermal energy to work (heat engines) must have two reservoirs at different temperatures. The engine can take heat from the reservoir at the higher temperature (source) and convert only some of the heat to mechanical energy; the rest of the heat will be expelled into the low temperature reservoir (sink). This is schematically illustrated by the following diagram.

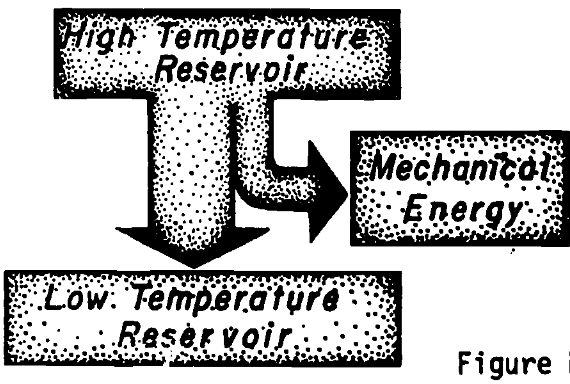


Figure B.1

The percentage of the heat taken from the high temperature reservoir which is converted to mechanical energy is called the efficiency. In a steam turbine system, what is the high temperature reservoir? What is the low temperature reservoir?

C. - A MACHINE THAT ALMOST WORKED

One could operate a machine which utilized the temperature difference between the warm surface waters and the cold deeper waters of the tropical ocean. Such a machine, designed and built by Georges Claude, is described in

(b) Heat cannot of itself flow from a cooler to a hotter body (a refrigerator is needed);

(c) Entropy of a closed system increases (net order is reduced).

These statements also imply a limitation on the efficiency of engines.

If Q_1 is taken from the high temperature reservoir and Q_2 is lost

$$Efficiency = \frac{Q_1 - Q_2}{Q_1}$$

If the only heat loss is the heat flowing to the low temperature reservoir <u>and</u> if the engine is built to operate on an ideal thermodynamic cycle (Carnot engine) the efficiency would still be limited by the temperatures T_1 and T_2 of the reservoirs.

$$\text{Max. efficiency} = \frac{T_1 - T_2}{T_1}$$

In this formula the temperatures are in absolute degrees. Real engines can only approach ideal ones and have incidental losses besides.

An excellent discussion of entropy may be found in "The Laws of Disorder" by George Porter, <u>Chemistry</u> Reprint #58. Reprints cost $1.00 for the first copy and 50¢ for each additional copy. Order from: Reprint Dept., Chemistry, 1155 Sixteenth St., N.W. Washington, D.C. 20036.

the interesting paperback book <u>Engineer's Dreams</u> by Willey Ley (Viking-Explorer Books, the Viking Press, New York). However, Claude had a severe limitation since the second law relates the maximum efficiency of the heat engine to the temperature difference between source and sink. When this difference is small (as it is between a surface temperature of 27° C and 5° C for deeper, tropical ocean waters), the law states that the efficiency will be low. In practice, when incidental losses due to friction, heat loss, and other losses were taken into account, his design fell very much short of the maximum possible efficiency stated by the second law. In fact, the net efficiency of Claude's machine was near zero. Discouraged, he sank all his machinery in the ocean; he was an idealist. If his machinery had worked only a little better, he would really have harnessed an unusual heat source.

D. - ORDER AND DISORDER

We have seen that it is absolutely necessary that some heat be lost to a cold region in order for a machine to produce usable mechanical energy. This is an inexorable consequence of the second law. We may look at this law from a somewhat different but perhaps even more revealing point of view, as follows. Heat may be thought of as "disordered energy"--it manifests itself in the chaotic motion of molecules and atoms; positions and motions of individual molecules and atoms cannot be predicted, only gross averages of many of them. The colder a body, the less disorder it represents. On the other hand mechanical energy (work) represents "ordered energy." A rotating wheel can be described relatively simply, and each of its parts follows a predictable path from moment to moment. Stated in a different form, the second law says the total order created by any actual engine will be less than the total disorder. In other words, useful work will be generated only at the expense of a net amount of disorder being created. An engine takes heat from a high temperature reservoir, thereby cooling it down somewhat and hence making it more ordered. But it more than makes up for this by heating up the low temperature reservoir. Being relatively cool to begin with, this reservoir becomes relatively more disordered upon being heated.

D.1. - THE TREND TOWARDS DISORDER AND WHAT WE MAY OR MAY NOT DO ABOUT IT

Left to themselves, almost all things tend towards disorder. This is the operation of the second law. For instance, when a hot body and a cold body touch each other, the heat always flows from hot to cold, and the net result is more disorder. Remember the bromine tubes? In the gaseous state the bromine atoms always spread throughout the tube so that their positions become less localized; the system becomes less ordered. The bromine atoms could never of themselves collect neatly in the end of the tube. The only way this can be done is by cooling them down; but as we shall now show, this cooling process is not inconsistent with the second law.

D.2. - REFRIGERATORS; DO THEY BUCK THE TREND?

A machine for cooling things down and thus producing some order (such as assembling water molecules into ice) is called a refrigerator. Below is a schematic diagram of the energy flow of a household refrigerator system. Notice that it ultimately takes some sort of engine to operate a refrigerator.

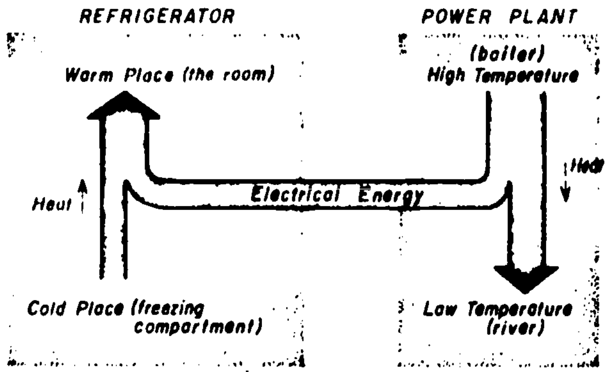


Figure D.1

It is indeed true that by transferring heat from a cold place to a warm place the refrigerator creates some order (for instance, water turns into ice cubes). But for this to happen, heat is transferred in some power plant from a high temperature place to a low temperature place. According to the second law, the net result will be an increased amount of disorder. Burning of fuel to produce heat in the power plant (i.e., releasing of chemical energy by breaking up ordered arrays of atoms in oil, for instance), more than makes up for the taking of heat away from the freezing water. A general way of expressing this is to say that localized order is produced only at the expense of order in the environment.

A hydroelectric power plant is a more subtle situation. The sun's heat cannot entirely be converted to potential energy of raised water. Some goes to warming the oceans (which ultimately radiate away heat to cool outer space). Even the potential energy of the water is not entirely converted to electric power. Some is converted to heat in the churning water below the dam.

D.3. - Experiment: A RUBBER BAND REFRIGERATOR

Stretch a larger size rubber band (1/4 inch or more flat width) to a length at which it

Some types of rubber bands seem to work better than others.

Materials and Equipment

large flat rubber bands, 1 for each student

begins to strongly resist additional pulling. Hold it in this position for approximately 1/2 minute, then quickly return it to its unstretched length. You will note that the rubber is now cooler than it was before you stretched it. (A sensitive place to test the temperature is the area just above your upper lip.) A tiny amount of heat has been removed from the rubber band and placed into the room. This is a one-step refrigeration process.

Chemical fuel is broken down by the body in order to supply the mechanical energy to stretch the rubber.

The cooled unstretched rubber band is a little more ordered than the room temperature unstretched rubber band. Has there been a net increase in order? Consider the effort required to stretch the band.

The boxes with the words "elongated band" and "normal length band" are not meant to show the comparative sizes or lengths of the band when it is stretched and then unstretched.

The process can be diagrammed as follows:

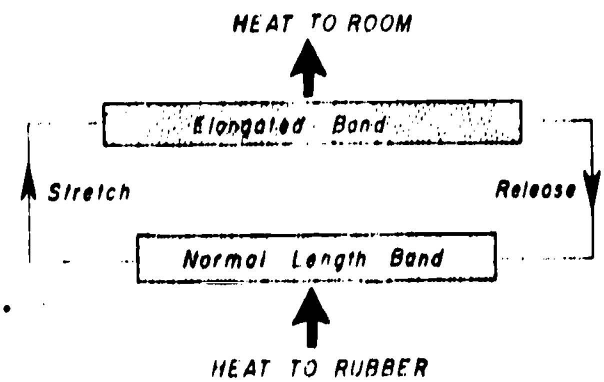


Figure D.2

This process also has a relationship to order and disorder. Rubber is made up of very long but intertangled helical molecules. When the rubber band is stretched the molecules are more or less lined up with one another, that is, they assume a more ordered configuration. When the band is released and allowed to resume its normal shape, heat is required to scramble the molecules again; the temperature drops, and this heat flows in from your upper lip, for instance.

E. - LIVING THINGS AND THE TREND TOWARDS DISORDER

As far as scientists have been able to tell, all living things, from the tiniest microbe to the largest whale, are made up of atoms and molecules. And you too--despite all the wonderful things you can do such as thinking and feeling and walking and laughing--are a collection of chemicals arranged in a complex and special way. What is the difference between you and some other complex collection of chemicals? If you were not alive, eventually your body chemicals would break down into simpler collections of atoms; others would react with one another until they were used up; ultimately all change and all motion would cease. This system of chemicals would fade away into an inert lump of matter. As the second law requires, this final decayed state would be more disordered than the original one.

These ideas are adapted from Erwin Schrodinger as given in his highly readable essay "What is Life" available in paperback (CAM 397, Cambridge University Press, Cambridge 1967). In shortened form it is given in the collection "The Mystery of Matter," Louise B. Young, Editor (Oxford University Press, New York 1965).

What then is the characteristic feature of life? It is this: that a living thing, being a wondrously complex and highly ordered collection of molecules, maintains itself against the inexorable trend towards disorder that marks the fate of other complex collections when left to themselves. It does this by eating, drinking, breathing, and continuous rebuilding of its body parts out of the substances it ingests. But what of the world outside a living organism, the environment upon which it depends for life? In total, the environment is very much degraded. Higher animals, for instance, utilize foods which store their energy in the chemical combinations of relatively highly ordered molecules. The energy is released in degraded form as heat, waste products, and motion (which ultimately becomes heat). Even green plants, which utilize radiant energy to build up complicated molecules from simpler ones, cannot overcome the dictates of the second law. Only a portion of the energy in sunlight is converted into chemical energy. The rest ultimately becomes heat.

The living organism maintains its complexity and continues to grow and perpetuate itself as long as it has a source of energy--

the sun in the case of green plants, animal or vegetable tissue in the case of animals. It takes in some energy and it rejects some; its wondrous "local order" is maintained only at the expense of order in the environment.

Exercises for Home, Desk, and Lab (HDL)

(1) What does the word "efficiency" mean to you?

(2) If the power input of an electrical motor was 600 watts and the power output was 400 watts, what would you say the efficiency of the motor was?

(2) 2/3 or 0.67 or 67%. Power is a measure of rated energy usage. Watts are joules per second. Thus wattage is a term not necessarily restricted to electrical situations.

(3) The water underneath the arctic ice has a temperature near 0° C, whereas the air above the ice may have a temperature near -40°C. Could one use thermal energy in the sea water of the arctic for running a heat engine?

(3) Yes. Since the air is colder, the air can be used as a heat sink.

(4) A mathematical formula for the maximum possible efficiency of a heat engine is

$$m = \frac{t_1 - t_2}{t_1 + 273°}$$

Here t_1 is the temperature of the source in °C, t_2 is the temperature of the sink in °C, and m is the maximum possible efficiency. What was the maximum possible efficiency of Georges Claude's heat engine? In practice, the efficiency of his machine was less than m.

(4) The absolute (Kelvin) scale of temperature is given by $T = t + 273$. Absolute zero is thus either $T = 0$ or $t = -273^o$ C

If $t_1 = 27^oC$
and $t_2 = 5^oC$ (see page 148)

$$\frac{27 - 5}{27 + 273} = \frac{22}{300} = 7\%$$

(5) a. What is the maximum possible efficiency of the heat engine described in problem (3)?

(5) a. If the engine were close to an ideal engine, m = 15%.

b. What would m be (using the formula in problem 4) if t_2 were -273° C? We are not making any statements as to whether or not it is possible to attain that temperature.

b. m = 100%

(6) Why is so much attention given the "fuel cell"? It has not been discussed here, but you may have learned about it in the newspapers, on TV, or in popular magazines.

(6) The fuel cell is <u>not</u> a heat engine; it converts the chemical energy of the fuel directly into electrical energy. Thus, it does not have the restriction on the maximum possible efficiency that a heat engine has.

(7) A thermocouple is an energy converter which operates between two temperatures. In the one you used in Chapter III these were the temperatures of the flame and room temperature. A Bunsen burner has maximum temperature of about 1500 °C. What maximum efficiency of heat to electrical conversion would you expect from this heat source? Do you see now why cooling the junction also produced electricity? Notice that no current flowed when the entire apparatus was at room temperature.

(7)

$$m = \frac{t_1 - t_2}{t_1 + 273^o} =$$

$$\frac{1500^oC - 22^oC}{1500^oC + 273^oC} =$$

$$\frac{1478}{1773} = 83\%$$

(If room temp. = 22°C.)

Cooling would likewise produce a temperature difference.

(8) Use the library to look up the actual operating efficiencies of various engines such as steam engines, internal combustion engines (gasoline and diesel), etc. Encyclopedia articles may be a good place to start.